SITE SELECTION PLAN AND INSTALLATION GUIDELINES FOR A NATIONWIDE DIFFERENTIAL GPS SERVICE

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PREFACE

This report is provided by the Institute for Telecommunication Sciences (ITS), National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce (DOC), to the Federal Highway Administration (FHWA), U.S. Department of Transportation (DOT), in fulfillment of Interagency Agreement Number DTFH61-93-Y-00110.

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ABSTRACT

The Global Positioning System (GPS), in its current form, is used within the transportation industry for vehicle tracking and navigation. With the advent of a nationwide differential GPS (DGPS) service, this role will expand to include public safety, infrastructure management, mayday services, and other yet unknown applications. The U.S. Department of Transportation is considering a nationwide DGPS service, modeled after the U.S. Coast Guard's Local Area Differential GPS system, to support surface applications. This service, when fully implemented, will provide accurate navigation and positioning information across the nation, promoting safety and efficiency in transportation and other fields.

The purpose of this document is to familiarize individuals responsible for the implementation of a DGPS system with the concept, configuration, operation, and performance of a nationwide DGPS service. The general requirements for DGPS broadcast site selection, and the recommended locations of broadcast sites, to complete nationwide coverage of the DGPS correction signal, are presented. The equipment required for broadcast site operation is described, along with the basic operation of this equipment.

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1 INTRODUCTION

The Global Positioning System (GPS), in its current form, is used within the transportation industry for vehicle tracking and navigation. With the advent of a nationwide differential GPS (DGPS) service, this role will expand to include public safety, infrastructure management, mayday services, and other yet unknown applications. The U.S. department of Transportation is considering a nationwide DGPS service, modeled after the U.S. Coast Guard's Local Area Differential GPS system, to support surface applications. This service, when fully implemented, will provide accurate navigation and positioning information across the nation, promoting safety and efficiency in transportation and other fields.

1.1 Background

The NAVSTAR Global Positioning System (GPS) is a space based radionavigation system which is operated for the Federal Government by the Department of Defense (DOD) and jointly managed by the DOD and Department of Transportation (DOT). GPS consists of a constellation of 24 satellites in 6 orbital planes; it provides accurate three-dimensional position, velocity, and precise time to users worldwide, 24 hours per day. GPS was originally developed as a military force enhancement system. Although still used in this capacity, GPS also provides significant benefits to the civilian community. In an effort to make GPS service available to the greatest number of users while ensuring that the national security interests are protected, two GPS services are provided. Positional accuracy available to certain authorized (i.e. military) users of GPS, designated as Precise Positioning Service (PPS), is 21 meters “two distance root mean square” (2drms). Due to encryption of the PPS signals, all other users have access to only the less accurate Standard Positioning Service (SPS). SPS accuracy without Selective Availability (SA) is 54 meters (2drms). With the addition of SA and Anti-Spoofing (AS) techniques, non-authorized user accuracy has been intentionally degraded to approximately 100 meters. Differential GPS (DGPS) augments SPS to provide higher accuracy positioning and increased integrity of the positioning information.

Recent studies of GPS and DGPS have documented the navigation and positioning needs of the GPS user community.[1,2,3] The information presented in these studies indicates that SPS accuracy of 100 meters does not meet most civil navigation and positioning requirements. Many users cited accuracy requirements of 10 meters or better for real time navigation and positioning applications, while surveying and mapping accuracy requirements were determined to be 1 meter or better. Most users would like to have the highest possible accuracy, if cost of the system was no object. Practical considerations of available technology and cost effective system implementation allow design of a nationwide DGPS service that will meet the requirements of a majority of the users. Although position accuracy is an important consideration to DGPS users, other factors are equally important to many users. Availability, defined as the percentage of time that the position signal is available to the user, and integrity, defined as the time required to alert the user to problems with the DGPS information, are also important factors in many applications. These elements can be improved with a nationwide DGPS service.

1.2 Purpose

The purpose of this document is to familiarize individuals responsible for the implementation of a DGPS system with the concept, configuration, operation, and performance of a nationwide DGPS service. The general requirements for DGPS broadcast site selection, and the recommended locations of broadcast sites, to complete nationwide coverage of the DGPS correction signal, are presented. The equipment required for broadcast site operation is described, along with the basic operation of this equipment. This document does not provide detailed engineering drawings or specifications for the DGPS broadcast site or the required equipment. Refer to the U.S. Coast Guard "Differential GPS Broadcast Equipment Technical Manual," GCF-W-1216-DGPS, and related documents for detailed information.

1.3 Benefits of a Nationwide DGPS Service

The benefits that will be derived from a nationwide DGPS service are numerous, affecting commerce, transportation, law enforcement, the environment, recreation, and many other aspects of daily life. Although the major emphasis of the service will be the nationwide improvement of public safety, there are many other areas that will realize benefits from this service. As one example, GPS provides a precise timing signal that even without augmentation is accurate enough to satisfy many of the timing requirements of the telecommunications industry and the power industry. But since these industries are required to satisfy their customers needs on a continuous 24 hour-a-day basis, they are hesitant to utilize GPS due to concerns about system reliability.[2] The ability of the DGPS service to provide integrity monitoring with rapid notification of problems, will relieve these concerns and make this valuable precise timing information available to these industries. In an entirely different area of operations, these industries will benefit from the accurate position information provided by DGPS, allowing accurate cataloging and maintenance of the nationwide infrastructure of power transmission lines and communications lines.

All modes of transportation including ships, boats, trucks, buses, automobiles, and even skiers and hikers, have requirements for position information, navigation, and safety that can be satisfied by a nationwide DGPS service. The requirements for transportation on the waterways are being met by the DGPS services being provided by the U.S. Coast Guard (USCG) and U.S. Army Corps of Engineers (COE). Expanding this system to a nationwide DGPS service will provide the same level of service for land transportation, where the potential users far out number the waterway users. The benefits that will be realized by land transportation users are as diverse as the industries that will use the service. Public transportation can increase the safety and efficiency of operations with real-time information on the location of buses. The trucking industry will be able to track their carriers across the nation, improving scheduling, reducing cost, and improving road safety. Hazardous material shipments will be tracked in real-time, avoiding environmental concerns. Small package shippers will control the movement of their deliveries and easily locate the destination of packages. All just-in-time manufacturers will benefit as they schedule on-time delivery of materials and distribution of product.

The Intelligent Transportation System (ITS) will be one of the larger markets for DGPS services, as navigation and location devices are incorporated into automobiles and light trucks. Several rental car agencies and some automobile manufacturers offer a GPS navigation system combined with a digital map as optional equipment. These systems also allow a driver to call for help in emergency situations. DGPS will make these navigation systems more accurate and useful. Navigation and route guidance for automobiles will be an important application of DGPS, but of even greater importance will be safety and security features. A DGPS receiver coupled with two way communications can provide the precise location of a vehicle in the event of an accident or emergency.

The railroads are evaluating the use of DGPS as a train location system on main lines, both inside and outside rail terminal areas, as a component of a Positive Train Control (PTC) system. PTC is targeted to improve railroad safety, increase rail system capacity, thereby improving productivity, and facilitate the growth of high speed passenger service and commuter service in the United States.[4]

One industry that will realize immediate benefits from the availability of nationwide DGPS service will be agriculture. The accurate positioning capability of DGPS will allow the seeding rate and application of pesticides and fertilizers to be adjusted. Environmental safety regulations require that certain pesticides not be applied near bodies of water, streams, or wells. DGPS will be particularly beneficial in aerial spraying of chemicals, providing the ability to apply the proper amount of chemical where it is needed and avoid areas that should not be sprayed, without exposing a flagman to the hazards of the chemical.

Another application where a nationwide DGPS service would have an immediate impact is surveying and mapping. The fact that DGPS can obtain an accurate location of a point, without a line of sight between adjacent surveyed points, as required by traditional survey techniques, provides an enormous cost reduction in the acquisition of accurate survey data. The nationwide DGPS service alone does not provide the real-time accuracy required for many surveying and mapping applications. However, the National Oceanic and Atmospheric Administration's program of Continuously Operating Reference Stations (CORS) is being installed at USCG and COE DGPS broadcast sites. CORS stores all data collected by the reference station and users can access this data electronically for post-processing that will provide position accuracies of 5 to 10 centimeters.[1] The National Park Service, the U.S. Fish and Wildlife Service, and other federal natural resource agencies plan to use DGPS for mapping and various natural resource inventory activities. Use of DGPS is more reliable and much less expensive than traditional surveying methods.[5]

Benefits of a nationwide DGPS service would be realized by a variety of recreational users including, pleasure boating, mountain climbing, skiing, hiking, and off road vehicles, as a few examples. These activities, particularly in remote areas, would benefit from the availability of accurate position information for guidance and navigation. Even more important is the life saving capability of avoiding getting lost, or if necessary, aiding search and rescue operations.

Police, Fire, and Ambulance services will benefit from the ability to navigate directly to the location of an emergency, reducing the time required to respond to potential life threatening situations. Emergency response to natural disasters such as floods, fires, and hurricanes will be improved with accurate position information. Relief activities and clean-up after natural disasters will also be more efficient with a nationwide DGPS service.

2

GENERAL DESCRIPTION OF DGPS BROADCAST SITE OPERATION

This nationwide DGPS service is based on the existing and proposed network of U.S. Coast Guard (USCG) and U.S. Army Corps of Engineers (COE) DGPS broadcast sites. This network, although designed to provide DGPS signal coverage to coastal areas, harbors, and inland waterways, by nature of the radiobeacon broadcast signal already provides coverage of over two thirds of the continental United States. A minimum number of additional DGPS broadcast sites are required to complete the nationwide coverage and provide the DGPS correction signal to all surface users. The broadcast sites that are added to the network will likely be added to the existing control stations that now monitor the USCG and COE DGPS broadcast sites. These redundant control stations provide real-time monitoring and control of the broadcast sites. Redundancy of the DGPS signal is obtained by designing the network of broadcast sites to provide overlapping coverage of the radiobeacon signal, so that a minimum of two DGPS correction signals can be received at most locations, nationwide.

2.1 GPS Constellation

The Department of Defense began development of the satellite-based GPS in 1973. The GPS constellation of 24 satellites in 6 orbital planes is now fully operational and provides accurate three-dimensional position, velocity, and precise time to users worldwide, 24 hours per day. The satellites complete an orbit every 11 hours and 56 minutes at an orbital height of 10,900 miles. The satellites are placed in their orbits so that a minimum of 5 will normally be observable by a user anywhere in the world. Positional accuracy available to authorized users of GPS, designated as Precise Positioning Service (PPS), is 21 meters (2drms). Authorized users employ the proper classified encryption keys and PPS-capable GPS receivers to extract the high accuracy encrypted signal. Due to encryption of the PPS signals, all non-authorized users have access to only the less accurate Standard Positioning Service (SPS). The DOD imposes Selective Availability (SA) on the SPS signal to deliberately reduce the navigation and timing accuracy of the system for non-authorized users. The military relies on SA and anti-spoofing (AS) procedures to deny full GPS accuracy to the enemy while maintaining use of the high accuracy signals for authorized users. SPS accuracy without SA is 54 meters (2drms). With the addition of SA and AS techniques, non-authorized user accuracy has been intentionally degraded to approximately 100 meters.

As soon as prototype GPS satellites were placed in orbit, long before full operational capability of the constellation, innovative civil users discovered economical applications for the available GPS signals. Industry, perceiving the growing demand for this service, developed and produced GPS receivers tailored to emerging civil market applications. As the civil use of GPS increased, the need for higher accuracy navigation and positioning signals was noted for many applications. This led to the development of DGPS, to augment the GPS signal and provide higher accuracy.

2.2 DGPS Description

DGPS is an enhancement of the GPS, through the use of differential corrections to the basic satellite measurements performed within the user's receiver. DGPS is based upon accurate knowledge of the geographic location of a reference station, which is used to compute corrections to GPS parameters and the resultant position solution. These differential corrections are then transmitted to DGPS users, who apply the corrections to their received GPS signals or computed position. For a civil user of SPS, differential corrections can improve navigational accuracy from 100 meters (2drms) to better than 10 meters (2drms). A DGPS reference station is fixed at a geodetically surveyed position. From this position, the reference station tracks all satellites in view, downloads ephemeris data from them, and computes corrections based on its measurements and geodetic position. These corrections are then broadcast to GPS users to improve their navigation solution.[6]

The nationwide DGPS service described in these guidelines is modeled after the USCG's medium frequency radiobeacon system, DGPS broadcast sites. This service will incorporate the proven technology of the USCG system and build on the existing network of DGPS broadcast sites, with only a minimum number of additional DGPS broadcast sites required to complete the nationwide coverage and provide the DGPS correction signal to all surface users, as described in chapter 5 of these guidelines.

The nationwide DGPS service is comprised of a land-based system consisting of four main components, as shown in Figure 2.1.

1. A reference station, placed at a precisely surveyed position, which receives and processes GPS satellite position information from orbiting GPS satellites, calculates corrections from the known position, and broadcasts these corrections via a radiobeacon to participating DGPS users in the radiobeacon's coverage area.
2. A control station, which remotely monitors and controls the DGPS broadcast sites via data communications lines.
3. A communications link, which provides data communications between the broadcast sites and the control stations.
4. User equipment, consisting of a GPS receiver and a radiobeacon receiver or combination GPS/radiobeacon receiver, which automatically applies the corrections to received GPS position information, to achieve position accuracies of better than 10 meters.

2.3 Beacon System Broadcast Characteristics

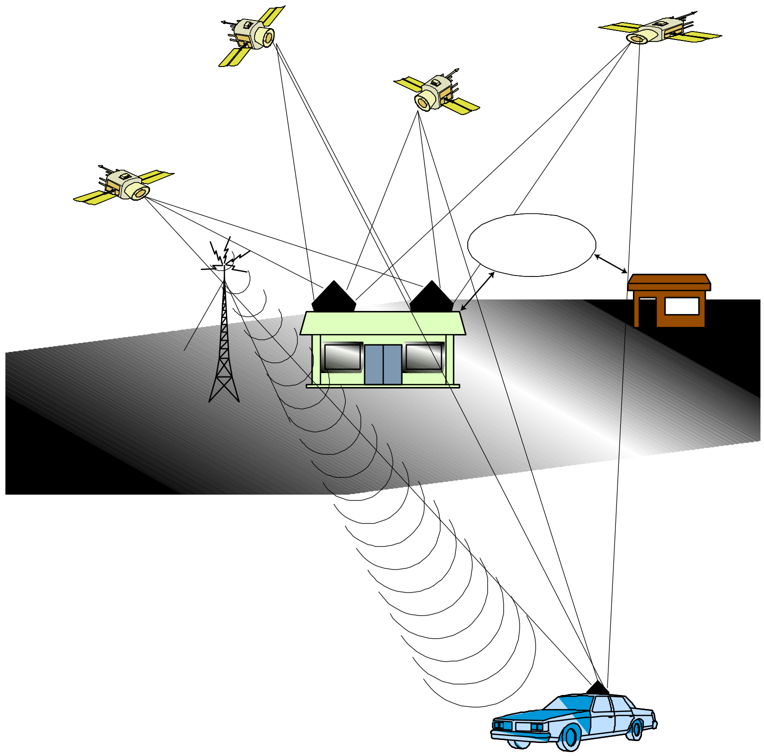


Figure 2.1. DGPS system.

The DGPS correction message, calculated by the broadcast site, is broadcast to the DGPS user by transmitting the information on a radiobeacon signal in the frequency range of 285 to 325 kHz. The eference station, placed at a precisely surveyed position, processes GPS satellite position information rom orbiting GPS satellites, calculates corrections from the known position of the reference station, nd modulates the correction messages onto the carrier of the radiobeacon. The corrections are ncoded as digital information using a form of phase modulation called Minimum Shift Keying MSK). MSK results in approximately a ±25 Hz shift in the carrier frequency of the radiobeacon (at 00 bits per second). The reference station generates two types of messages, Radio Technical ommission for Maritime use messages (RTCM) and Reference Station Integrity Monitor messages (RSIM).

RTCM type 9 messages contain corrections to the pseudoranges of the various satellites in view and are modulated onto the carrier of the radiobeacon for transmission to users' equipment. The RTCM format also allows DGPS site data to be flagged as unhealthy or un-monitored, providing notification to the user of any potentially unreliable data. User receivers equipped with a DGPS beacon receiver can interpret the RTCM messages and automatically produce the corrected positional information whenever they are within range of a DGPS beacon. Accuracy of differentially corrected GPS signals is specified to be within 8 meters 95% of the time. Actual accuracy achieved by the user may depend upon the quality of their equipment and their distance from the DGPS site, but is typically much better than 8 meters.

RSIM messages contain information about the reference station's health and the reference station's confidence in the corrections generated. This confidence level is computed by the station's integrity monitor. RSIM messages are not broadcast, but are used for communication between the reference station, the integrity monitor, and the control station.

During normal operation the minimum field strength of the DGPS broadcast signal will be 75 microvolts per meter (uV/m) in the specified coverage area, at a transmission rate of 100 bits per second.[7] The location of broadcast sites, recommended in chapter 5, and the operating parameters of the beacon transmitters, are designed to provide this field strength over the specified coverage area. The recommended location of broadcast sites will provide signal coverage from at least two beacon transmitters, at most locations, nationwide. The reception of the beacon signal is dependent on the capabilities of the user's beacon receiver. Most beacon receivers will provide reception of the signal with field strengths of 10 uV/m or less, above the background noise level. The user receiver should always select the closest satisfactory beacon.

2.4 DGPS System Performance

The three major elements of DGPS system performance that are of concern to the user are accuracy, availability, and integrity. The position accuracy of the DGPS service will be within 8 meters (2drms) in all specified coverage areas. In most cases the accuracy will be better than 8 meters. A reasonable approximation for determining the achievable accuracy at a given point is to take the typical error at a short distance from the broadcast site (on the order of 0.5 meters), add an additional meter of error for each 150 kilometers of separation from the broadcast site, and add an additional 1.5 meters of error for the user equipment.[7] The actual position accuracy achieved is highly dependent on the user equipment, and the capability of this equipment is constantly being improved. From this it is easy to see that even at a distance of 300 kilometers from the broadcast site, a position accuracy of less than 5 meters can be obtained.

Availability of a given broadcast is defined as the percentage of time in a one month period during which a DGPS broadcast site transmits a healthy correction signal at the specified output level. The DGPS service was designed for, and is operated to maintain a broadcast availability level which exceeds 99.7%, assuming a complete and healthy satellite constellation is in place.[7]

The integrity of the broadcast DGPS correction signal is monitored continuously by the broadcast site, and at any time a problem is detected with the broadcast site equipment or the calculated correction, an alarm is transmitted to the user. The time from fault detection to transmission of an alarm to the user is a maximum of 4 seconds at the 100 bits per second transmission rate.

2.5 DGPS Signal Coverage

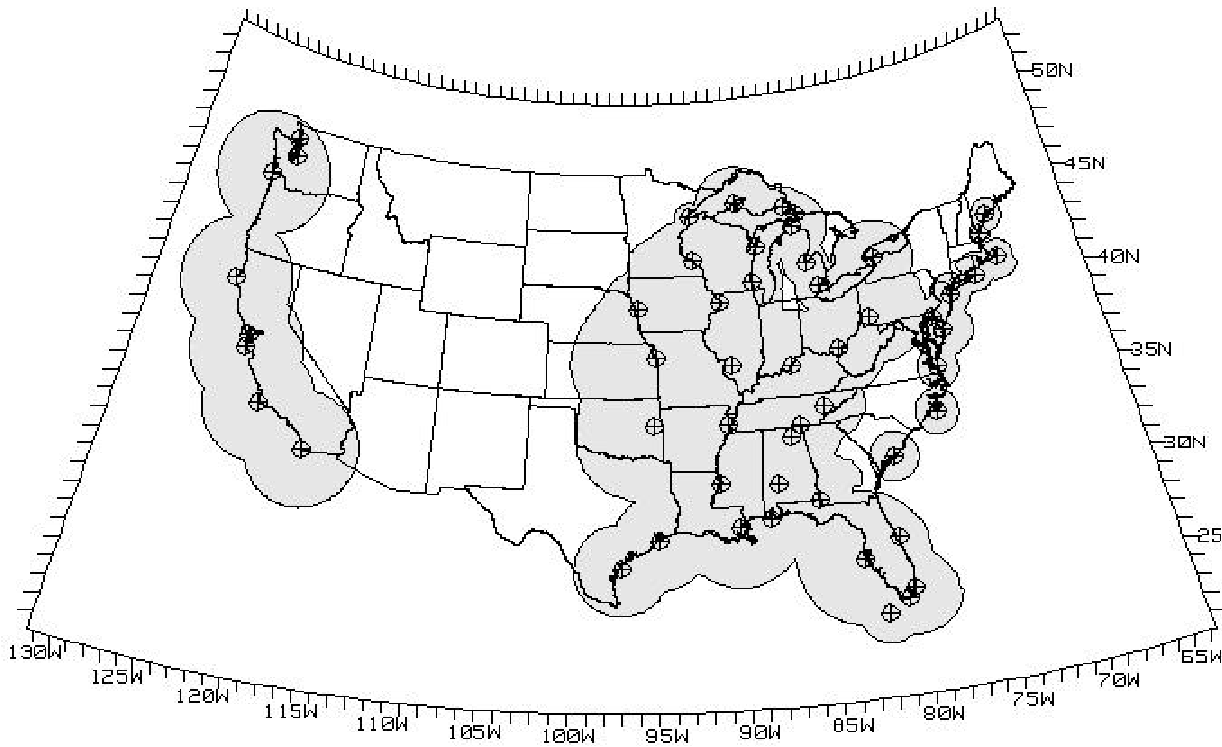


Figure 2.2. Existing DGPS radiobeacon signal coverage.

The network of DGPS broadcast sites now in operation or proposed by the USCG and COE provides DGPS signal coverage to coastal areas, harbors, and inland waterways. The network was originally designed to provide signal coverage for harbor and harbor approach areas, and other critical waterways for which the USCG provides aids to navigation. The service has been extended to provide coverage for the Great Lakes and the Mississippi River, resulting in a network of DGPS broadcast sites that provide radiobeacon signal coverage to over two thirds of the continental United States, as shown in figure 2.2.

The completion of a nationwide DGPS service that will provide signal coverage over the continental United States will require adding a minimum number of DGPS broadcast sites to this existing network. The signal coverage for the radiobeacon transmitters is aided by the use of the medium frequency 285 to 325 kHz band, which provides the advantages of a large coverage range with low power transmitters, and a minimum effect of terrain features on the propagation of radio waves. Redundancy of the DGPS signal is obtained by designing the network of broadcast sites to provide overlapping coverage of the radiobeacon signal so that at least two DGPS correction signals can be received at most locations, nationwide. The recommended location of additional broadcast sites and the operating parameters of these sites is covered in chapter 5 of these guidelines.

2.6 Control Stations

There are two existing DGPS control stations operated by the USCG, one in Alexandria VA., and one in Petaluma CA. The Alexandria VA. station handles all east and gulf coast sites and the Petaluma CA. station handles all west coast sites including Alaska and Hawaii. In the event of a failure at a control station, the other control station is capable of assuming operation of the total network. The broadcast sites that are added to the network will likely be added to these existing control stations, providing real-time monitoring and control of all broadcast sites.

The control stations are monitored 24 hours a day. Should any broadcast site develop problems, the control station will first take steps to correct the problem, and if appropriate, notify the local support of the malfunction. The control station software runs on the Coast Guard Tactical Advanced Computer system. This software allows the control station to check the status of each broadcast site, and provides control of the output modules at the control station, allowing remote resetting of the broadcast site equipment.

The control station is capable of logging raw DGPS data from broadcast sites for statistical analysis. This process allows the control station to verify the positions of the reference station and integrity monitor antennas to detect configuration errors, and to check for errors introduced by multipath signals or ionospheric conditions.

3
DGPS BROADCAST SITE CONFIGURATION

This chapter provides an overview of the subsystems and equipment that make up a DGPS broadcast site. Several of these broadcast sites will be required, strategically positioned across the country, to achieve a nationwide DGPS service. This information does not include detailed engineering drawings or specifications for the DGPS broadcast site or the required equipment. Refer to the U.S. Coast Guard "Differential GPS Broadcast Equipment Technical Manual," GCF-W-1216-DGPS, and related documents for detailed information.

3.1 DGPS System Architecture

Functionally, a DGPS broadcast site consists of several, interconnected subsystems as shown in Figure 3.1.

The function of the dual reference stations (Reference Station A and Reference Station B) is to compute corrections for GPS satellite signals and output these corrections to a radiobeacon transmitter at the prescribed radiobeacon transmitting frequency. The DGPS design incorporates redundant reference stations to provide backup in the case of a failure in one of the reference stations.

The dual integrity monitors (Integrity Monitor A and Integrity Monitor B) monitor the integrity of the broadcast DGPS correction signal. Integrity Monitor A provides integrity monitor system feedback to Reference Station A and Integrity Monitor B provides integrity monitor system feedback to Reference Station B. If either the Reference Station or Integrity Monitor of one Reference Station/Integrity Monitor pair fails, the other Reference Station/Integrity Monitor pair can be brought on-line.

The DGPS broadcast site monitor provides remote monitor and control capability for the DGPS broadcast site from the control station. Reference Station Integrity Monitor messages (RSIM) are transmitted to the control station via the X.25 communications network. RSIM messages contain information about the reference station's health and the reference station's confidence in the corrections generated. This information allows the control station to monitor the status of the reference station and control the operation of the redundant systems.

The packet assembler/disassembler is the communication center for all equipment at the DGPS broadcast site. All data messages between subsystems within the DGPS broadcast site and between the DGPS broadcast site and the control station are routed through the packet assembler/disassembler.

The data service unit provides the interface between the packet assembler/disassembler at the DGPS

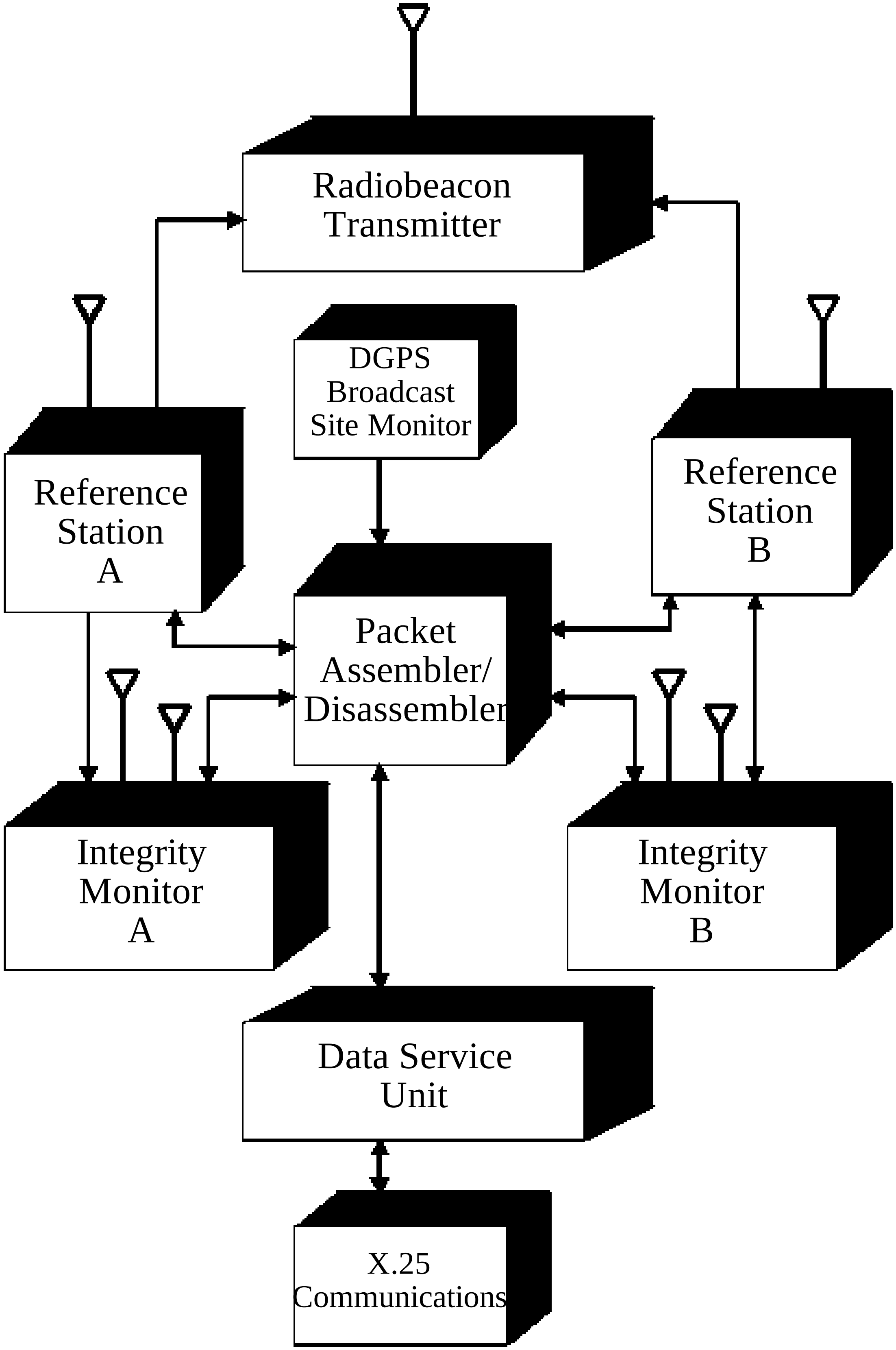


Figure 3.1. DGPS system block diagram.

broadcast site and the X.25 network to allow remote control and monitoring of the DGPS broadcast site from the control station. The data service unit is owned by the X.25 service provider (local telephone company).

The radiobeacon transmitter is the subsystem of the DGPS broadcast site equipment that amplifies and broadcasts the DGPS corrections to users in the coverage area.

3.2 DGPS Broadcast Site Equipment Relationship

Figure 3.2 shows a full DGPS broadcast site configuration and the physical connections between equipment at the site. The major components are:

(a) The DGPS equipment rack provides mounting and interconnections for the DGPS broadcast site suite of equipment.

(b) The radiobeacon equipment rack provides mounting for the radiobeacon transmitter.

(c) Reference mast 1 provides mounting for the reference station A GPS receive antenna, the integrity monitor B GPS receive antenna, and the integrity monitor B MSK receive antenna.

(d) Reference mast 2 provides mounting for the reference station B GPS receive antenna, the integrity monitor A GPS receive antenna, and the integrity monitor A MSK receive antenna.

(e) The antenna tuning unit provides the interface between the radiobeacon transmitter and the broadcast antenna.

(f) The radiobeacon antenna broadcasts the DGPS correction signal to users in the coverage area.

(g) Various environmental sensors may be connected to the DGPS equipment rack to provide monitoring of conditions at the DGPS broadcast site. These sensors include:

Intrusion sensors
Fire sensors
Temperature sensors
Humidity sensors
Power status sensors

3.3 DGPS Equipment Rack

A 19" equipment rack is installed at each DGPS broadcast site. The rack is designed to reduce electromagnetic interference (EMI) from external electrical or electronic devices or systems by 30

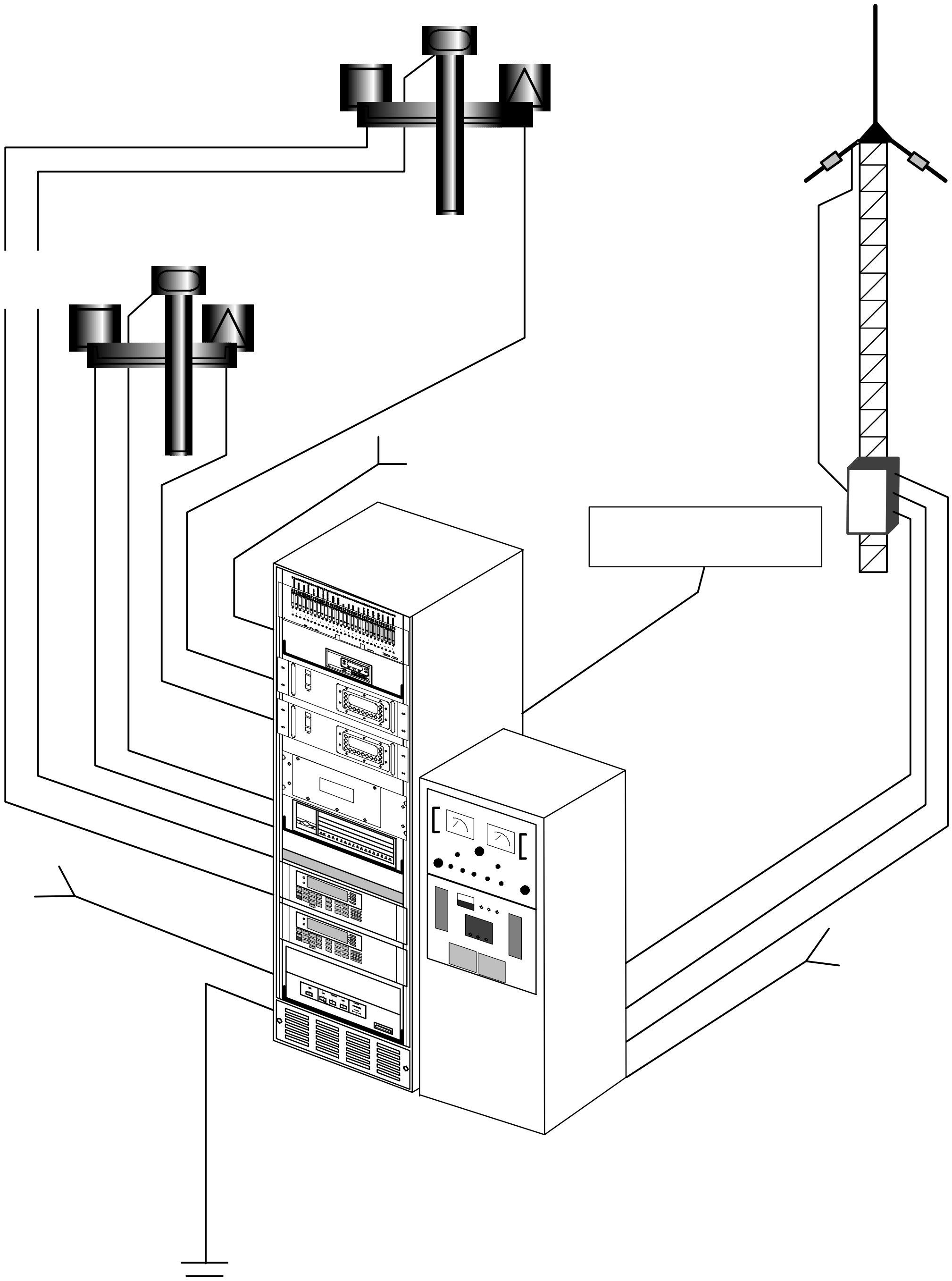


Figure 3.2. DGPS broadcast site equipment relationship.

decibels (dB). All DGPS broadcast site equipment is installed in this rack except reference masts and associated components, the radiobeacon transmitter, the broadcast antenna and associated components, and the various environmental sensors. A 300 cubic foot per minute fan is mounted on the bottom front of the rack and provides cooling air to all installed DGPS equipment. See Figure 3.3 for equipment layout within rack. A description of each component mounted in the rack is given below.[8]

Input/Output (I/O) Panel

The input/output panel contains sixteen digital input modules and eight output modules. Its function is to provide sensor input and control output for the DGPS broadcast site monitor. Sensor input and control output are provided through the junction panel, located directly behind the input/output panel.

Junction Panel

The junction panel's main purpose is to transfer input and output interconnection points to the top rear of the equipment rack rather than the front. This panel design simplifies the input and output wire runs, improves signal grounding, allows for intrusion alarm delay relay mounting, and eases installation by providing improved access for sensor wiring.

Data Service Unit

The data service unit is owned by the X.25 service provider (local telephone company). The data service unit's purpose is to provide an interface between the packet assembler/disassembler at the DGPS broadcast site and the X.25 network to allow remote control and monitoring of the DGPS broadcast site from the control station. The data service unit receives its 110 Vac power from the relay panel, located directly behind the data service unit. The data service unit sends and receives data via a high speed data transfer cable connected to the packet assembler/disassembler. The data service unit communicates at a rate of 9600 bits per second (bps) over the X.25 network.

Relay Panel

The function of the relay panel is to allow reset/on/off AC power control of any or all of the following equipment: reference station A/B, integrity monitor A/B, packet assembler/disassembler, and data service unit, based on control station remote commands through the DGPS broadcast site monitor. The relay panel consists of a relay wired to an AC outlet for each piece of equipment mentioned above. The relay panel receives AC power from the uninterruptible power system, and control input from the junction panel.

Reference Stations A and B

The DGPS broadcast site is outfitted with two dual-frequency, 12-channel reference stations. Each reference station is composed of a GPS reference receiver and a minimum shift keying (MSK) modulator. Its primary function is to compute corrections, known as pseudorange corrections (PRC), for GPS satellite signals and output these corrections in the MSK format to a radiobeacon transmitter at the prescribed radiobeacon transmitting frequency. The DGPS design incorporates redundant reference stations. Although both reference stations provide signal input to the radiobeacon transmitter, the radiobeacon transmitter only broadcasts corrections from one reference station at a time. If one reference station fails, the radiobeacon transmitter automatically shifts to the other reference station and will continue to broadcast correction until the faulty reference station can be repaired or replaced.

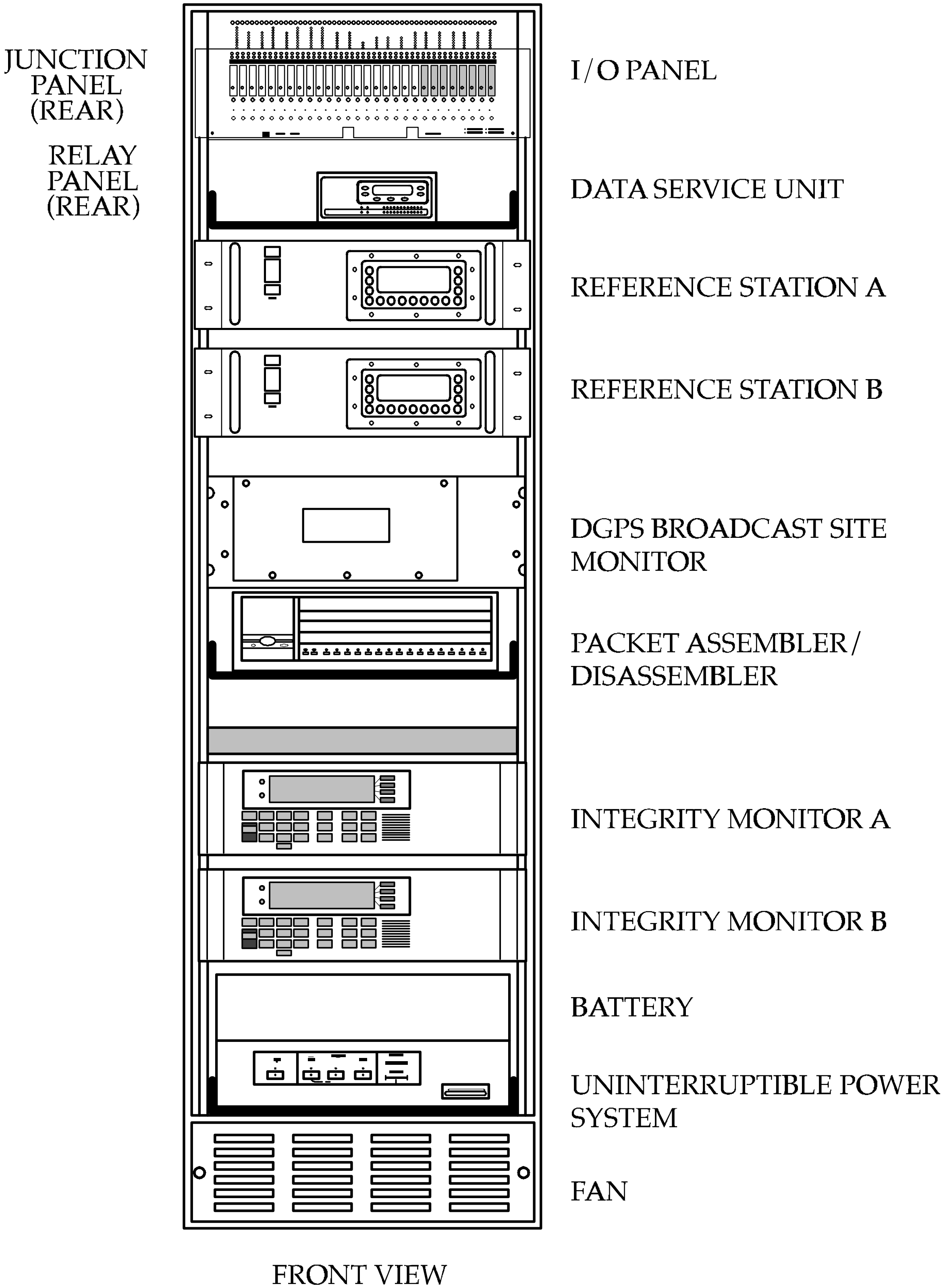


Figure 3.3. DGPS equipment rack configuration.

The reference stations receive AC power from the Relay Panel. This connection allows remote reset/on/off capabilities.

Each reference station has four communications ports to communicate with the control station and other pieces of equipment in the DGPS rack.

The reference station receives satellite information from the GPS antenna and outputs the MSK signal to the radiobeacon transmitter.

DGPS Broadcast Site Monitor
The function of the DGPS broadcast site monitor is to provide remote monitor and control capability for the DGPS broadcast site from the control station. The DGPS broadcast site monitor is the main unit of the site monitoring suite of equipment, which includes the input/output panel, junction panel, relay panel, environmental sensors, and all interconnecting cabling and wiring. The DGPS broadcast site monitor is connected by a ribbon cable to the input/output panel. The DGPS broadcast site monitor supplies 12 VDC to the junction panel. Remote control and monitoring of the DGPS broadcast site monitor is achieved through connections to the packet assembler/disassembler. The DGPS broadcast site monitor receives 110 Vac power from the uninterruptible power system.

Packet Assembler/Disassembler
The packet assembler/disassembler functions as the central communication hub for all equipment at the DGPS broadcast site. Although the packet assembler/disassembler, data service unit, and X.25 network are important for the flow of information to and from the control station, the DGPS broadcast site will still function properly if the packet assembler/disassembler, data service unit, or X.25 network fails. The packet assembler/disassembler's 110 Vac power cord is connected to the relay panel. The packet assembler/disassembler is equipped with twelve data ports. Each data port is connected to a specific communications port within the DGPS equipment rack and provides data transfer between the control station and that port.

Integrity Monitor A and B
As the name implies, the DGPS broadcast site integrity monitor monitors the integrity, or truth, of the DGPS broadcast information. Both integrity monitors monitor the MSK broadcast from the radiobeacon antenna. Integrity monitor A provides integrity monitor system feedback to reference station A and integrity monitor B provides monitor system feedback to reference station B. The integrity monitors identify their associated reference station by the reference station ID number encoded into the broadcast. If either the reference station or integrity monitor of one reference station/integrity monitor pair fails, the other reference station/integrity monitor pair can be brought on-line.

Each integrity monitor's 110 Vac power cord in connected to the relay panel. This allows remote reset/on/off control of the integrity monitors. The integrity monitor has four data ports. The integrity monitor receives satellite information from the GPS antenna, and the MSK signal from the MSK antenna.

Uninterruptible Power System
The function of the uninterruptible power system is to provide on-line uninterruptible AC power to the vital equipment located in the DGPS equipment rack. The uninterruptible power system does not provide uninterruptible power to the equipment rack cooling fan or the radiobeacon rack.

The uninterruptible power system has a battery backup unit, located directly above, which will provide a minimum of 10 minutes power at full load. A typical DGPS installation operates at approximately 20% of the uninterruptible power system's rated load. In the event of a loss in primary power, the uninterruptible power system will give the DGPS broadcast site monitor time to notify the control station of the site's power status but will not, by itself, allow the site to continue DGPS broadcasts.

The uninterruptible power system is monitored by the DGPS broadcast site monitor for AC power and inverter status. The uninterruptible power system has a bank of 4 outlets providing uninterruptible AC power and 1 outlet providing filtered AC power to the reference stations, integrity monitors, packet assembler/disassembler, and data service unit indirectly through the relay panel. From another uninterruptible outlet, the uninterruptible power system provides power directly to the DGPS broadcast site monitor.

The description above is for the standard USCG DGPS broadcast site uninterruptible power system. In some installations where a DGPS broadcast site may be installed, the uninterruptible power system and battery backup unit will be available external to the DGPS equipment rack. In this case the external uninterruptible power system should be incorporated into the system to provide the functions described above.

Hand-held Terminal (not shown in Figure 3.3)
This unit provides an interface between the technician and the DGPS broadcast site monitor microprocessor. It allows the technician to observe a limited number of processor functions during normal operations. The technician may configure and/or initialize the DGPS broadcast site monitor with this terminal. The hand-held terminal connects to a jack on the front panel of the DGPS broadcast site monitor through the attached ribbon cable. The hand-held terminal should only be connected during maintenance or configuration routines. The hand-held terminal should not be left connected to the DGPS broadcast site monitor when a technician is not at the site because a power failure would interfere with the DGPS broadcast site monitor's remote monitor and control capabilities.

3.4 Radiobeacon Equipment Rack

The half-height radiobeacon rack contains the radiobeacon transmitter. The radiobeacon transmitter, antenna tuning unit, and broadcast antenna are essential to the DGPS broadcast site operation, since this is the equipment that amplifies and broadcasts the DGPS corrections to users in the coverage area. Depending on the site, the radiobeacon transmits up to 62.5, 250, or 1000 watts. Each site transmits in the single carrier mode (with no morse code identifier) on an assigned frequency between 285 and 325 kHz. The reference station MSK signal is inserted into the radiobeacon's exciter in place of the radiobeacon's center carrier crystal. Reference station A's signal is inserted into the radiobeacon's side A exciter and reference station B's signal into the side B exciter. The DGPS broadcast site monitor handles reset/on/off control and transmit status monitoring of the radiobeacon.

The standard radiobeacon transmitter used at USCG DGPS broadcast sites is the Nautel marine radiobeacon transmitter, but the operation of the DGPS broadcast site is not dependent upon any specific type of transmitter. At some non-Coast Guard sites, MF transmitters other than the Nautel series are in use.

3.5 Reference Antenna Masts

Each site includes two reference masts, designated reference mast #1 and reference mast #2. Each reference mast supports one reference station (GPS receive) and two integrity monitor (GPS receive and MSK receive) antennas. All reference masts are either standard, (shown in Figure 3.4) or nonstandard.

There are two types of standard reference masts: a self-supporting Rohn tower, and a 60', 18" outer diameter (O.D.) steel pipe, driven 30' into the ground. The 18" O.D. reference mast is used in extremely poor soil conditions that would not adequately support the Rohn reference mast concrete foundation. Standard Rohn reference masts are either 10', 20', or 30' high.

Nonstandard reference masts are those installations in which the above reference station/integrity monitor antennas are mounted to a structure other than a standard reference mast, such as a building roof or existing tower.

3.6 Radiobeacon Broadcast Antenna

The existing DGPS broadcast sites use a variety of radiobeacon broadcast antennas, depending on the conditions at the individual site. The broadcast antenna and its associated ground plane are designed to provide the desired signal coverage from a broadcast site. An antenna tuning unit, located at the base of the antenna tower, couples the radiobeacon signal from the radiobeacon transmitter to the broadcast antenna, and is designed to match the characteristics of the individual antenna. A ground plane of radial wires, buried in the ground, is installed at each broadcast antenna. The number and length of these radials is determined by antenna characteristics and local ground conductivity. The length of the radials determine the physical plot required for the DGPS broadcast site, and in some cases require a 15-acre or greater plot.

The recommended additional DGPS broadcast sites required to complete the nationwide coverage of the DGPS correction signal are covered in chapter 5 of these guidelines. It is recommended that a majority of these sites be located at existing Ground Wave Emergency Network (GWEN) radio transmitter sites where the broadcast antenna and associated infrastructure are in place, avoiding a major expense of installing a DGPS broadcast site.

3.7 Other DGPS Broadcast Site Equipment

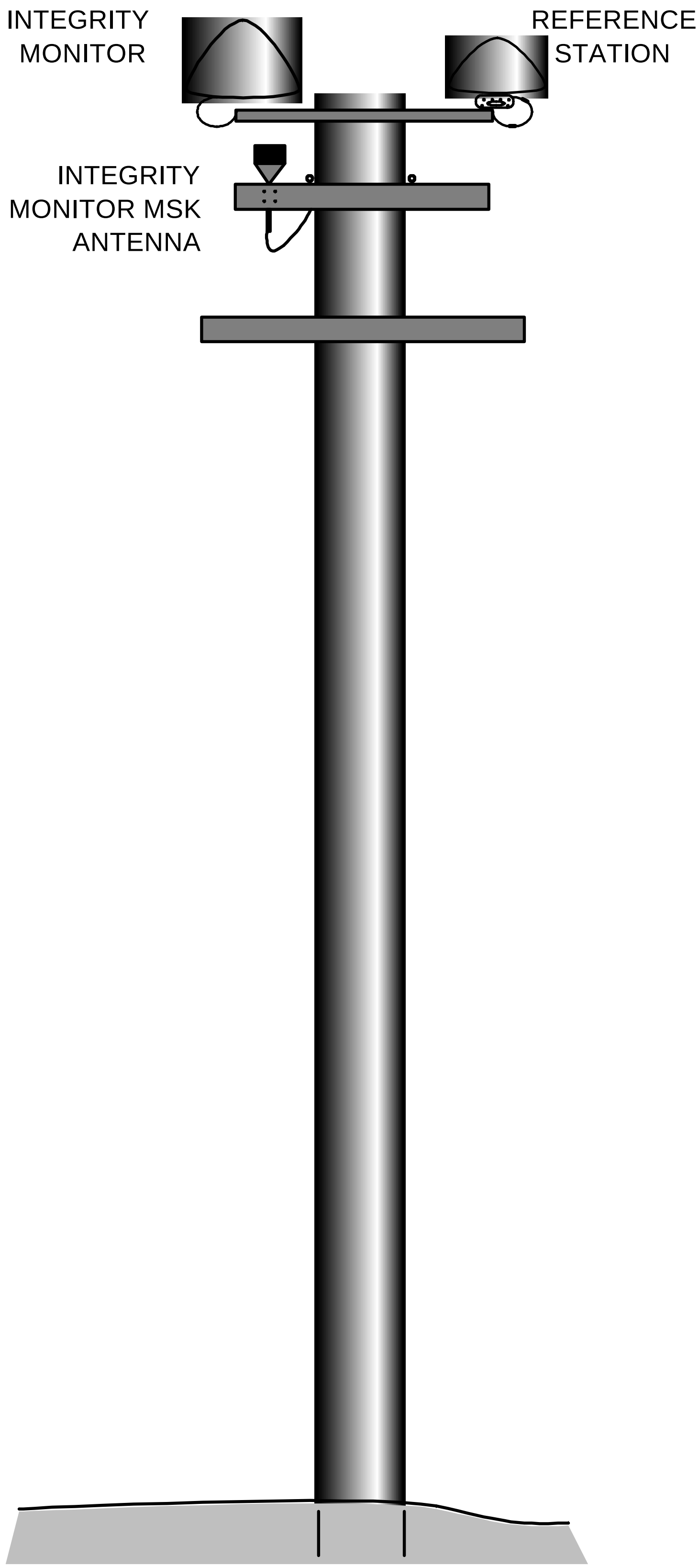


Figure 3.4. Standard reference mast and antenna mounting.

In addition to the equipment described above, there are several other pieces of equipment at the DGPS site. Some of this equipment is essential for proper operation of the DGPS broadcast site. Other equipment improves the function or reliability of the DGPS broadcast site, but is not considered essential.

Equipment Shelters

Where possible existing buildings or shelters should be utilized to house the DGPS broadcast site equipment. If a new shelter is required, a fiberglass building with dimensions: 8 feet high, 15 feet wide, and 10.5 feet deep, is recommended. Equipment shelters are available at the GWEN radio transmitter sites recommended to complete the nationwide DGPS network.

Environmental Control

Environmental controls are required at each DGPS broadcast site, designed to maintain a temperature at the DGPS equipment rack of between 40 - 90 degrees Fahrenheit and a humidity below 80 percent. The required equipment will be determined by conditions at an individual site. Environmental controls are available at the GWEN radio transmitter sites recommended to complete the nationwide DGPS network.

Emergency Generator

At sites where power is not reliable, an emergency generator should be installed to provide sufficient backup power to the radiobeacon and DGPS rack in the event of a prolonged commercial power outage. The generator should be rated between 125 and 165 percent of the site's load, including environmental controls. At the GWEN radio transmitter sites recommended to complete the nationwide DGPS network, this emergency generator is in place.

Lighthouse Power Controller

At the existing DGPS broadcast sites where an emergency generator is installed at the site, the DGPS broadcast site monitor is connected to a lighthouse power controller, providing remote monitoring of the site's power status at the control station. The function of the lighthouse power controller is to start the emergency generator upon sensing a loss of commercial power and, when the generator output is stable, provide emergency power until the return of commercial power. The lighthouse power controller provides emergency power within 4 minutes of sensing a loss of commercial power. At sites added to complete the nationwide DGPS network, a power controller would need to be interfaced to the DGPS broadcast site monitor and provide the functions described above.

Power Conditioner and Filter

A power conditioner and filter should be part of the overall site design. This equipment will mitigate potential problems caused by brownouts, power fluctuations, and noise on the commercial power line.

Fire Detection/Suppression System

If a site is equipped with a fire detection/suppression system, the DGPS broadcast site monitor may be connected to provide remote monitoring at the control station. The DGPS broadcast site monitor is designed to monitor the fire detection status. It is not designed to provide remote control of the suppression system.

Communications/Telephone

One high speed data line is required for data service unit at the DGPS broadcast site. This is a 9600 bps, 4-wire line, as part of the X.25 Packet Switching Service, supplied by the local service provider. One voice telephone line should be available for voice communications.

4

DGPS Broadcast Site Performance

The success of the DGPS radiobeacon broadcast service can be credited to the efforts of the U.S. Coast Guard (USCG). The USCG developed this service to provide mariners with reliable position accuracies of better than 10 meters when navigating in harbor and harbor approach areas of continental U.S., Alaska, Hawaii, and Puerto Rico. The service was designed around the proven technology of the radiobeacon transmitter and made use of the existing radiobeacon infrastructure. The service was soon expanded, by the USCG and the U.S. Army Corps of Engineers (COE), to include coverage of the Great Lakes and Mississippi River and other uses such as rescue operations, dredging operations, and hydrographic surveys became common. Although the broadcast site performance factors described below were initially developed for navigation on the waterways,[9] they apply equally well to the nationwide DGPS service, as coverage of the DGPS radiobeacon correction signal is expanded over the country.

4.1 Accuracy

With the full satellite constellation in place the position accuracy of the DGPS service will be within 10 meters (2drms) in all specified coverage areas. The accuracy of the DGPS correction signal depends on precise knowledge of the position of the GPS antennas at each broadcast site. At each of the USCG and COE DGPS radiobeacon broadcast sites, the National Geodetic Survey has installed geodetic monuments referenced to the NAD 83 Coordinate System to provide this position accuracy. Since the DGPS reference station utilizes these monuments, the user's differentially-determined position solution is inherently transformed into the NAD 83 Coordinate System. Geodetic monuments will be required at new DGPS radiobeacon broadcast sites for accurate positioning of the reference station antennas.

A reasonable approximation for determining the achievable accuracy at a given point is to take the typical error at a short baseline from the reference station (on the order of 0.5 meters), add an additional meter of error for each 150 kilometers of separation from the reference station (broadcast site) and add an additional 1.5 meters of error for the user equipment. Some high-end user sets are achieving pseudorange measurement accuracies of less than 30 centimeters for a given pseudorange in the absence or the abatement of multipath. Hence, one can readily see that for the user with high-end equipment who is within 300 kilometers from a given broadcast site, the achievable accuracy is better than 5 meters (2drms). Note that although this higher accuracy is achievable, the present system computes the protection limit for the integrity alarm at 8 meters (2drms).

4.2 Availability

Availability for a given broadcast is defined as the percentage of time in a one-month period during which a DGPS broadcast transmits healthy correction signals at the specified output level. The current DGPS navigation service was designed for, and is operated to, maintain a broadcast availability level which exceeds 99.7%, assuming a complete and healthy satellite constellation is in place.

The most significant availability specification is the availability at the user location which is simply referred to as user availability. It is the most difficult to quantify due to the nature of the atmospheric noise. Quantitative analysis shows that for a given coverage area it lies somewhat higher than 98%, but empirical data with the latest MSK receiver technology need to be collected over a period of several years in order to ascertain a more exact number. In applications where the user availability is required to be high, the user can employ complementary technologies such as map-matching, dead reckoning, or inertial navigation to provide very high availability of position information, even if the DGPS broadcast correction signal is interrupted for short periods.

The phenomena which mainly determine the user availability level of the service in a given coverage area are equipment reliability and broadcast link robustness. The use of redundant equipment is utilized in many aspects of the system and most areas can be covered by redundant broadcast sites, as shown in chapter 5. The signal strength and structure utilized is designed to overcome the time variant levels of atmospheric noise and thus provide the specified level of availability. Since the reference station/integrity monitor sets can operate autonomously without regular intervention from the control center, the communication lines have a reduced effect on system availability. Each broadcast site provides the redundancy of two reference station/integrity monitor sets. Under certain circumstances the switch over between sets will occur automatically and under other circumstances it will require intervention from the control center.

4.3 Integrity

System integrity is built upon the foundation of the integrity monitors. The integrity monitors will ensure the integrity of the broadcast pseudorange corrections and broadcast an alarm message to the user if the corrections fall outside preset limits. The user equipment plays a significant role in assuring that the integrity of the system is preserved. It should be capable of automatically selecting the appropriate radiobeacon from the available broadcast signals.

The function of the integrity monitor that is important to the user is the alarm that is broadcast when any error is detected, and the critical factor in some applications is the time required for the user to receive the alarm message. The time from when an error is detected to when the user equipment is alarmed by the broadcast is less than 4 seconds for 100 bps transmission rates. A complete description of alarm conditions and the alarms broadcast to the user is given in the "Broadcast Standard for the USCG DGPS Navigation Service."[9]

5

DGPS BROADCAST SITE SIGNAL COVERAGE

A nationwide DGPS service will require DGPS broadcast sites distributed across the country to provide the DGPS correction signal to all surface users. In order to determine the optimum location of these DGPS broadcast sites, a medium frequency radio propagation model was utilized along with the operating parameters of each DGPS broadcast site, to predict the signal coverage of the individual broadcast sites. The signal coverages of the individual sites were then combined to determine the predicted signal coverage that would be obtained with a nationwide network of DGPS broadcast sites. The radio propagation model that was used was validated by conducting signal strength measurements at several operating U.S. Coast Guard (USCG) DGPS broadcast sites.[10] The signal coverage predicted for these radiobeacon transmitters is aided by the use of the medium frequency 285 to 325 kHz band, which provides the advantages of a large coverage range with low power transmitters and a minimum effect of terrain features on the propagation of radio waves. During normal operation the minimum field strength of the DGPS broadcast signal will be 75 microvolts per meter (uV/m) in the specified coverage area. Although the effects of terrain on the signal strength is minor in this frequency band, shadowing by terrain may reduce the signal level in some very rugged areas.

In order to provide the most cost effective solution to the implementation of a nationwide DGPS service, maximum use was made of existing DGPS broadcast sites and other infrastructure. The signal coverage obtained is presented below in four stages:

1. Existing USCG and U.S. Army Corps of Engineers (COE) DGPS signal coverage
2. Existing Ground Wave Emergency Network (GWEN) radio broadcast site signal coverage
3. Additional sites required for nationwide signal coverage
4. Additional sites required for redundant signal coverage

5.1 USCG and COE DGPS Signal Coverage

The basis of the nationwide DGPS service is the network of DGPS broadcast sites now in operation or proposed by the USCG and COE, providing DGPS correction signal coverage to coastal areas, harbors, and inland waterways. The network was originally designed to provide signal coverage for harbor and harbor approach areas, and other critical waterways for which the USCG provides aids to navigation. The service has been extended to provide coverage for the Great Lakes and the Mississippi River, resulting in a network of DGPS broadcast sites that provide radiobeacon signal coverage to over two thirds of the continental United States, as shown in

Figure 5.1. The locations and operating parameters of the DGPS broadcast sites making up this network is described in Table 5.1.

5.2 Existing GWEN Radio Transmitter Site Signal Coverage

Table 5.1 USCG and COE DGPS broadcast site information.

Broadcast Site	Frequency	Power	Latitude	Longitude
	kHz	W (ERP)	(N)	(W)
Sandy Hook, NJ	286	5	40 28 17	074 00 42
Key West, FL	286	4	24 00 00	082 00 00
Fort Stevens, OR	287	27	46 12 18	123 57 21
Pigeon Point, CA	287	27	37 10 55	122 23 35
Portsmouth Harbor, ME	288	3	43 04 15	070 42 37
Cape Henry, VA	289	7	36 55 38	076 00 24
Cape Canaveral, FL	289	35	28 27 35	080 32 35
Louisville, KY	290	170	38 15 00	085 45 00
Cheboygan, MI	292	15	45 39 10	084 28 00
Cape Mendocino, CA	292	27	40 26 29	124 23 56
English Turn, LA	293	42	29 52 44	089 56 31
Montauk Point, NY	293	7	41 04 02	071 51 38
Fort Macon, NC	294	7	34 41 52	076 40 59
Virginia Key, FL	295	2	25 15 00	080 30 00
Galveston, TX	296	22	29 19 45	094 44 10
Wisconsin Point, WI	296	1	46 42 16	092 01 01
Huntington, WV	296	170	38 50 00	082 30 00
Milwaukee, WI	297	10	43 00 06	087 53 18
Cape Henlopen, DE	298	22	38 46 36	075 05 16
Charleston, SC	298	11	32 45 28	079 59 35
Upper Keweenaw, WI	298	20	47 13 21	088 37 18
Omaha, NE	298	13	41 46 42	095 54 39
Sallisaw, OK	299	170	35 30 00	095 00 00
Mobile Point, AL	300	17	30 13 38	088 01 24
Saginaw Bay, MI	301	4	43 37 43	083 50 17
Whidbey Island, WA	302	4	48 18 46	122 41 46
Point Loma, CA	302	27	32 39 54	117 14 33
Aransas Pass, TX	304	22	27 50 18	097 03 33
Kansas City, KS	305	170	39 10 00	094 45 00
Knoxville, TN (TVA)	306	170	45 41 18	119 08 35
Neebish Island, MI	309	3	46 19 17	084 09 02
Reedy Point, NJ	309	3	39 33 41	075 34 11

Table 5.1 (continued) USCG and COE DGPS broadcast site information.

Broadcast Site	Frequency	Power	Latitude	Longitude
	kHz	W (ERP)	(N)	(W)
Memphis, TN	310	35	35 27 56	090 12 21
Point Blunt, CA	310	2	37 51 12	122 25 04
Rock Island, IA	311	120	42 00 30	090 14 00
Egmont Key, FL	312	42	27 36 16	082 45 40
Pittsburgh, PA	312	170	40 15 00	080 00 00
Vicksburg, MS	313	60	32 19 53	090 55 11
Andrews Locks, FL	314	170	31 00 00	085 00 00
Brunswick, ME	316	7	43 53 42	069 56 17
St. Paul, MN	317	120	44 18 15	091 54 14
Whitefish Point, MI	318	3	46 46 17	084 57 29
Detroit, MI	319	7	42 17 49	083 05 41
Millers Ferry, AL	320	170	32 05 24	087 23 44
Point Arguello, CA	321	27	34 34 39	120 38 38
Miami, FL	322	25	25 43 56	080 09 38
Sturgeon Bay, WI	322	10	44 47 40	087 18 49
Youngstown, NY	322	30	43 14 10	079 01 03
St. Louis, MO	322	120	38 36 41	089 45 31
Robinson Point, WA	323	3	47 23 15	122 22 29
Gunthersville, AL	323	170	34 30 00	086 20 00
Chatham, MA	325	5	41 40 17	069 57 02
Chattanooga, TN	325	170	35 05 00	085 40 00

The existing radio transmitter sites, recommended here for incorporation into the nationwide DGPS service, are part of the Ground Wave Emergency Network (GWEN), owned by the Air Force Air Combat Command. The GWEN sites are existing Federal government assets, and these radio broadcast sites are scheduled for decommissioning in the same time frame that the nationwide DGPS service would be installed. The Air Force currently has 57 GWEN transmitter sites, covering the continental U.S. Fifteen of the GWEN sites are at locations that would be useful in completing the nationwide, single coverage of the DGPS correction signal. The GWEN sites currently transmit at 150 to 175 kHz and could be easily modified to accept the 285 to 325 kHz radiobeacon signal. The equipment required at the DGPS broadcast sites would be installed in the existing enclosures, the existing broadcast antenna would be used, and the cost and delay of land acquisition and environmental impact statements would be avoided.

The GWEN transmitter sites include the following features, all applicable to the DGPS broadcast site.

(a) A 299-foot broadcast antenna tower

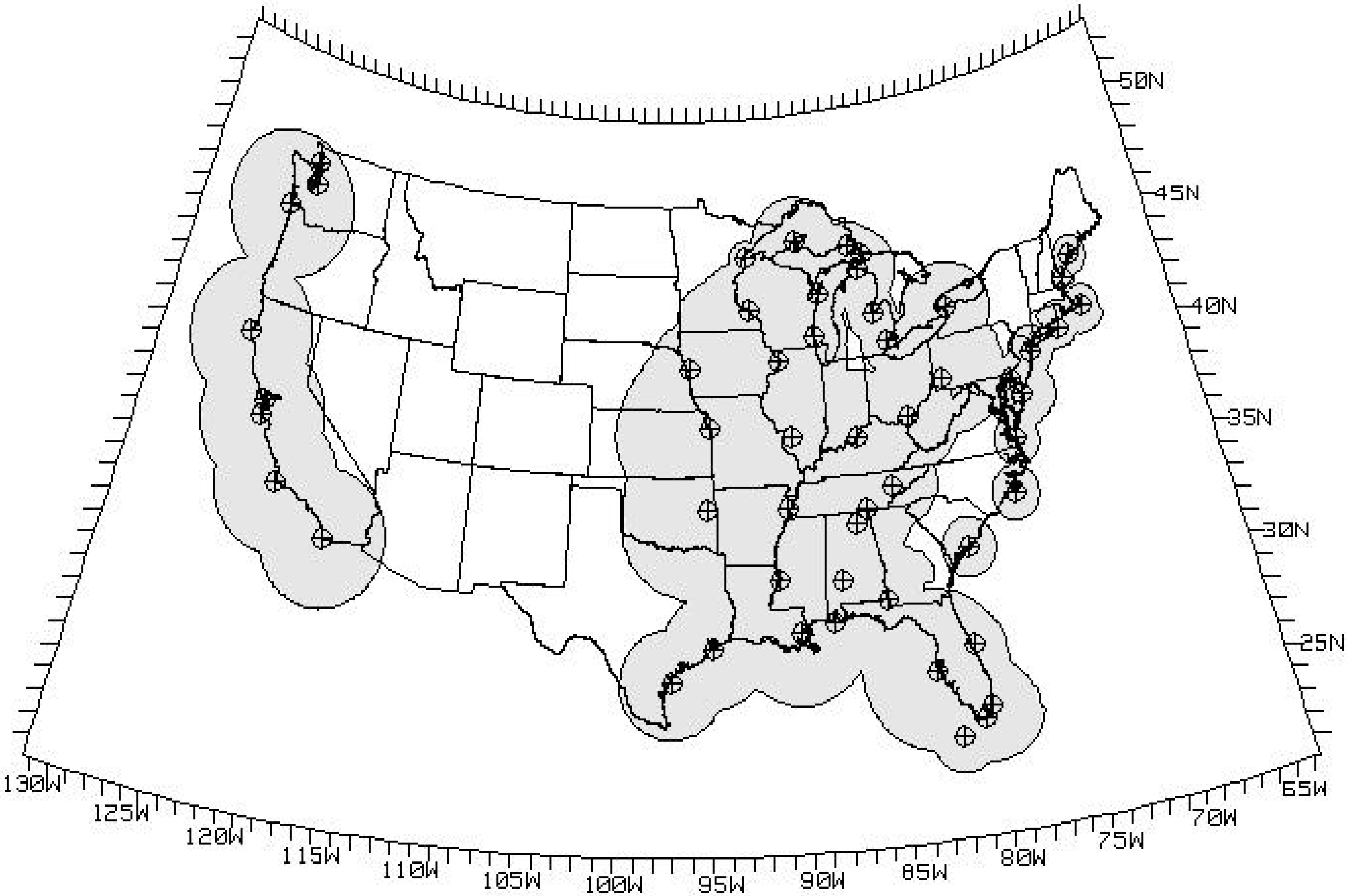


Figure 5.1. Predicted signal coverage for existing USCG and COE DGPS broadcast sites.

(b) A large ground plane, designed for ground conductivity conditions at the site
(c) An antenna tuning unit enclosure at the base of the tower
(d) Two equipment shelters
(e) Electronic racks that will accept the DGPS equipment
(f) All utilities that are required for operation of the DGPS broadcast site
(g) Air conditioning and environmental controls
(h) Back-up power generators
(i) Above ground fuel storage tanks
(j) Security enclosures with intrusion alarms

The DGPS correction signal coverage provided by adding these 15 existing GWEN radio transmitter sites to the existing USCG and COE DGPS broadcast sites is shown in Figure 5.2. The locations and operating parameters of these broadcast sites is described in Table 5.2. In order to obtain the signal coverage shown in these figures for added broadcast sites, it will be necessary to design the transmitter at each broadcast site to provide the signal field strength indicated in the tables, at a distance of 10 kilometers from the site.

5.3 Additional Sites Required for Nationwide Signal Coverage

As shown in Figure 5.2, with 15 existing GWEN radio broadcast sites added to the USCG and COE DGPS broadcast sites, there are still a few areas that are not covered by the DGPS correction signal. This requires the addition of seven additional USCG type DGPS broadcast sites, and increasing the transmitter power at six USCG broadcast sites, to complete the nationwide coverage. The DGPS correction signal coverage with these 7 additional sites is shown in Figure 5.3. The locations and operating parameters of these additional sites are described in Table 5.3. It should be noted that the recommended DGPS broadcast site locations that have been added to complete the nationwide coverage were selected as optimum locations, and at these frequencies location of the site up to 10 miles from the optimum location will have very little effect on the nationwide coverage plan.

5.4 Additional Sites Required for Redundant Signal Coverage

The nationwide DGPS signal coverage shown in Figure 5.3 was derived to insure that all locations, nationwide, would have access to the DGPS correction signal. Increasing the coverage so that most locations nationwide will be covered by at least two DGPS broadcast sites, providing additional signal availability, requires the addition of sixteen more DGPS broadcast sites, and increasing the transmitter power at nine USCG broadcast sites. The redundant DGPS correction signal coverage with these 16 additional sites is shown in Figure 5.4. The locations and operating parameters of these additional sites is described in Table 5.4.

5.5 Frequency Assignments

Existing USCG and COE DGPS broadcast sites have an operating frequency assigned in the 285 to 325 kHz band. These assignments are noted in Table 5.1. The operating frequencies recommended for new DGPS broadcast sites have been selected to avoid interference with other DGPS broadcast

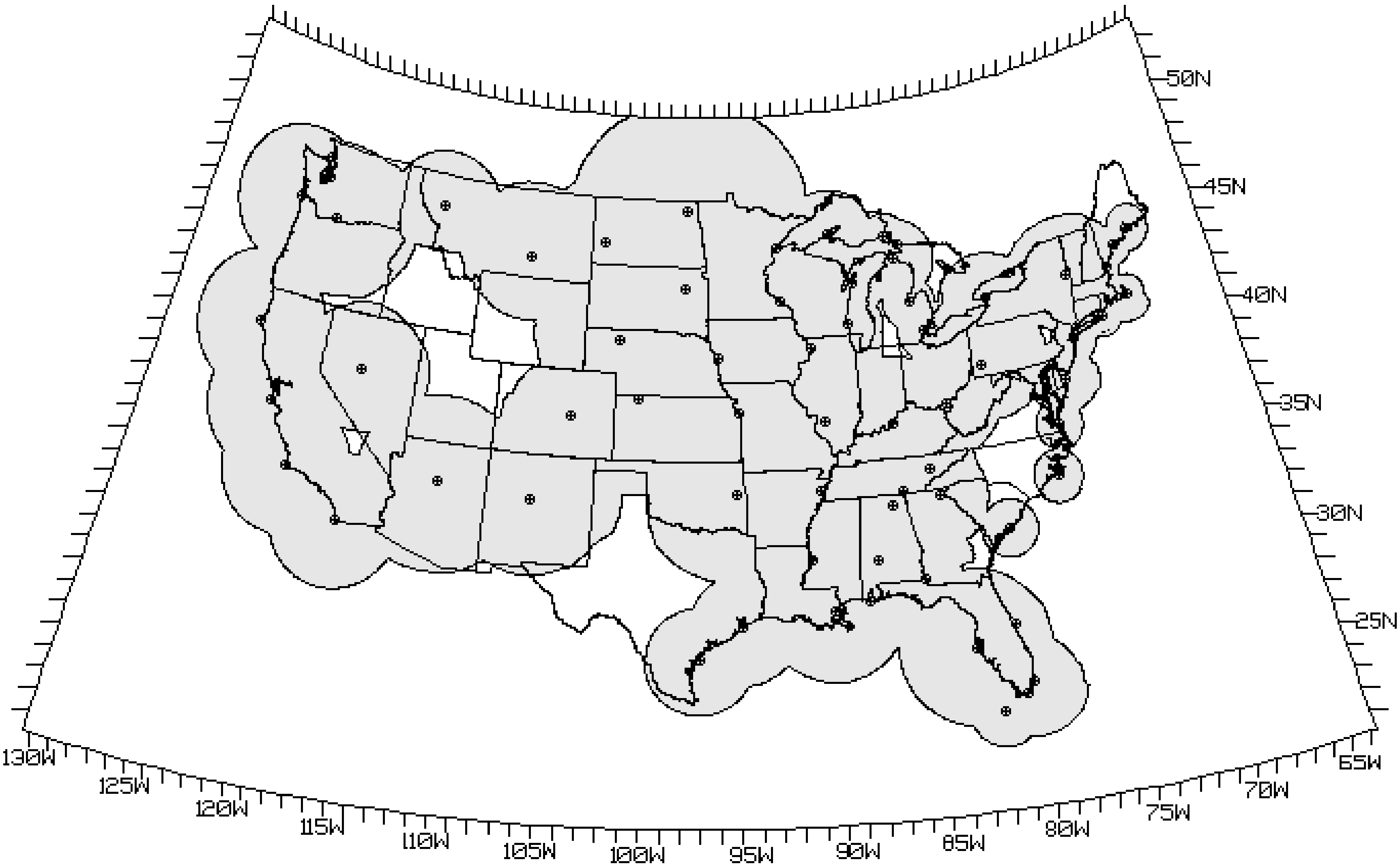


Figure 5.2. **Predicted signal coverage for 15 existing GWEN radio transmitter sites added to the USCG and COE DGPS broadcast sites.**

Table 5.2 Existing GWEN radio transmitter site information.

Broadcast Site	Frequency kHz	Power W (ERP)	Field Strength dbuV/m @ 10 km	Latitude (N)	Longitude (W)
Goodland, KS	286	300	82.6	39 49 39	100 39 49
Ronan, MT	287	170	80.1	47 34 47	114 06 50
Penobscot, ME	290	13	68.9	44 26 07	068 47 22
Kirtland, NM	291	300	82.6	34 57 26	106 29 32
Appleton, WA	300	300	82.6	45 46 55	121 19 34
Macon, GA	301	300	82.6	34 41 39	083 33 38
Medora, ND	306	100	77.8	46 54 22	103 16 29
Edinburg, ND	307	300	82.6	48 33 31	097 47 04
Clark, SD	309	300	82.6	44 56 03	097 57 38
Whitney, NE	310	300	82.6	42 30 00	102 00 00
Austin, NV	312	300	82.6	39 30 00	117 30 00
Billings, MT	313	300	82.6	45 58 19	107 59 47
Flagstaff, AZ	319	300	82.6	35 13 18	111 49 06
Hudson Falls, NY	324	300	82.6	43 16 13	073 32 19
Pueblo, CO	325	300	82.6	38 51 54	104 34 31

Table 5.3 Additional DGPS broadcast site information.

Broadcast Site	Frequency kHz	Power W (ERP)	Field Strength dbuV/m @ 10 km	Latitude (N)	Longitude (W)
Odessa, TX	285	170	80	31 50 00	102 20 00
Arlington, TX	294	170	80	32 40 00	097 00 00
Jackson, WY	301	170	80	44 00 00	110 06 00
Greensboro, NC	301	170	80	36 00 00	079 30 00
Duchesne, UT	303	170	80	40 36 00	110 24 00
El Paso, TX	316	170	80	32 00 00	106 20 00
Sun Valley, ID	320	170	80	43 00 00	115 00 00

sites, and with Federal Aviation Administration beacons, civil radiobeacons licensed by the Federal Communications Commission, Canadian DGPS beacons, Canadian aviation beacons, and Mexican aviation beacons that operate in this frequency band. The recommended frequencies are noted in Tables 5.1 through 5.4. Since frequency assignments in this band are dynamic, the situation will need to be reevaluated when application for a frequency assignment is made at a specific location.

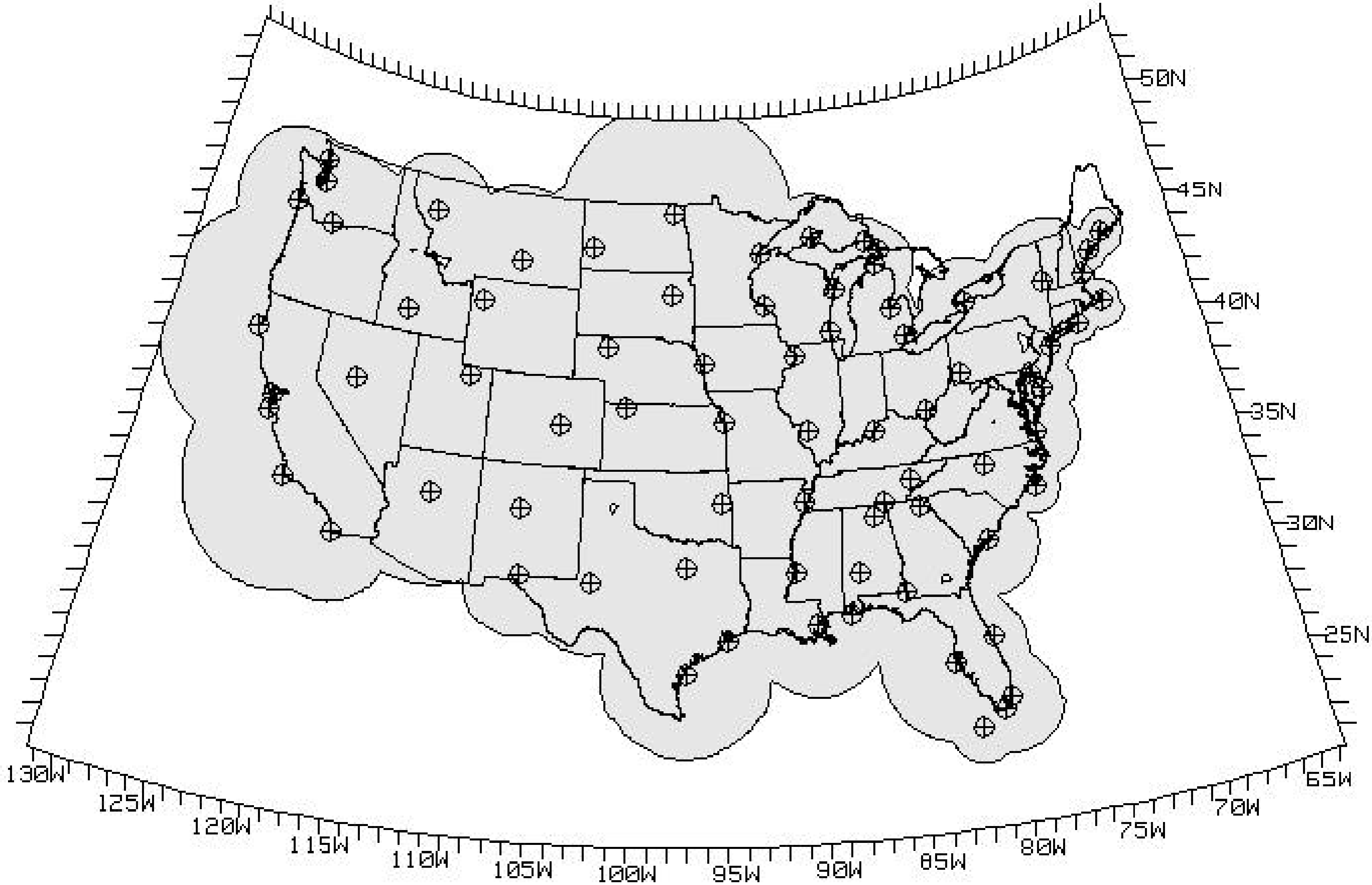


Figure 5.3. Predicted signal coverage with 7 additional DGPS broadcast sites.

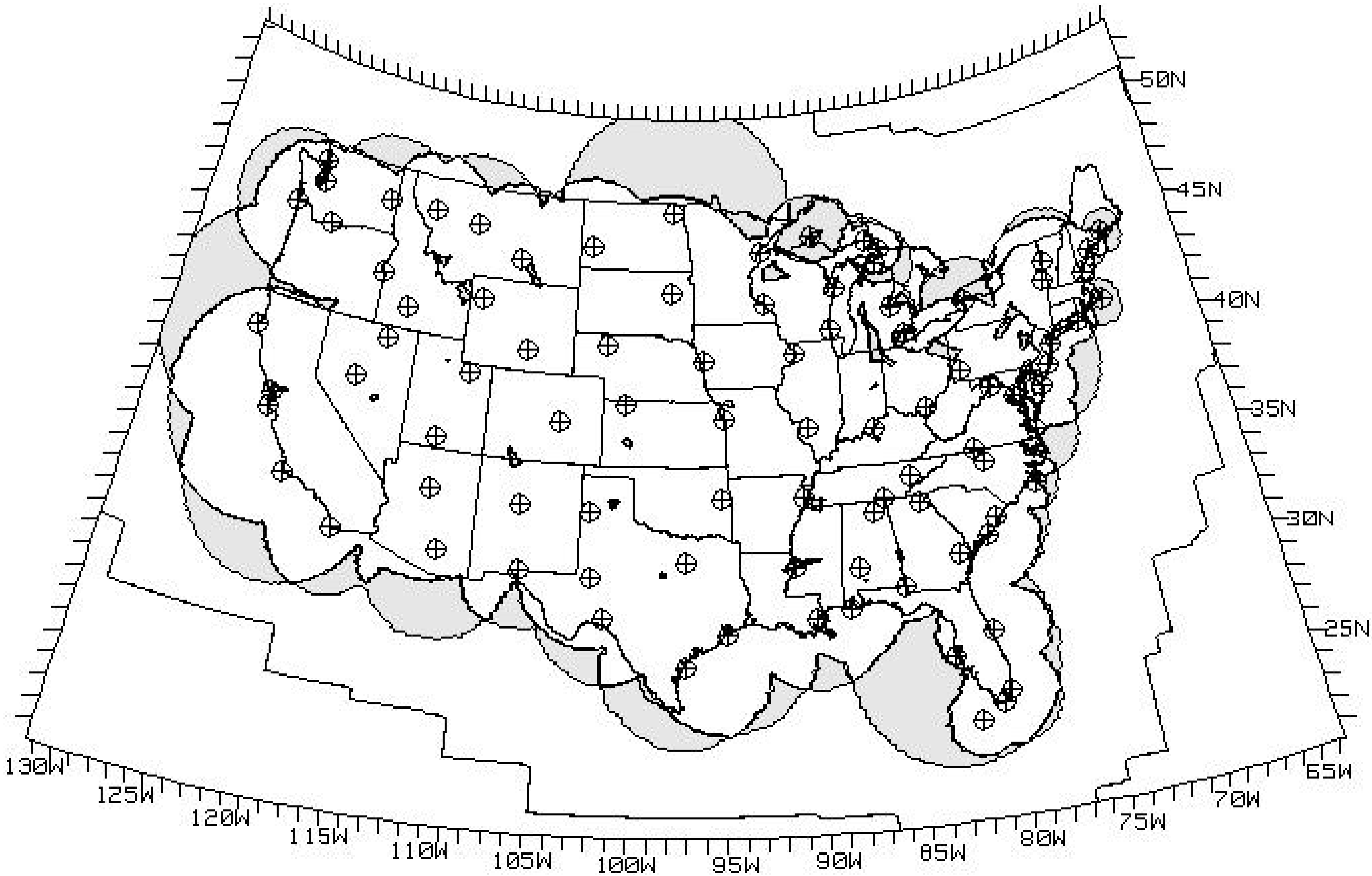


Figure 5.4. Nationwide redundant signal coverage.

Table 5.4 Additional redundant coverage DGPS broadcast site information.

Broadcast Site	Frequency	Power	Field Strength	Latitude	Longitude
	kHz	W (ERP)	dbuV/m @ 10 km	(N)	(W)
GWEN Sites					
Savanna, GA	285	300	82.6	32 08 22	081 41 49
Kensington, SC	292	300	82.6	33 28 51	079 20 35
Egg Harbor, NJ	311	300	82.6	39 36 12	074 22 16
Great Falls, MT	314	300	82.6	47 18 13	111 10 19
Goldwein, VA	315	300	82.6	38 37 09	076 52 51
Spokane, WA	316	300	82.6	47 31 10	117 25 21
Summerfield, TX	318	300	82.6	34 49 28	102 30 43
Other Sites					
Tucson, AZ	286	170	80	32 30 00	111 00 00
West, TX	289	170	80	30 00 00	101 30 00
Weiser, ID	291	170	80	44 20 00	117 00 00
Rawlins, WY	297	170	80	42 00 00	107 00 00
South, UT	307	170	80	37 30 00	112 00 00
Winchester, VA	307	170	80	39 15 00	078 15 00
Martinsville, VA	310	170	80	36 40 00	080 00 00
Middleburg, VT	314	170	80	44 00 00	073 15 00
North, NV	315	170	80	41 30 00	116 00 00

5.6 Individual DGPS Broadcast Site Signal Coverage

The figures 5.5 through 5.42 show the predicted signal coverage for individual DGPS broadcast sites that will be required to complete the signal coverage for a nationwide DGPS service.

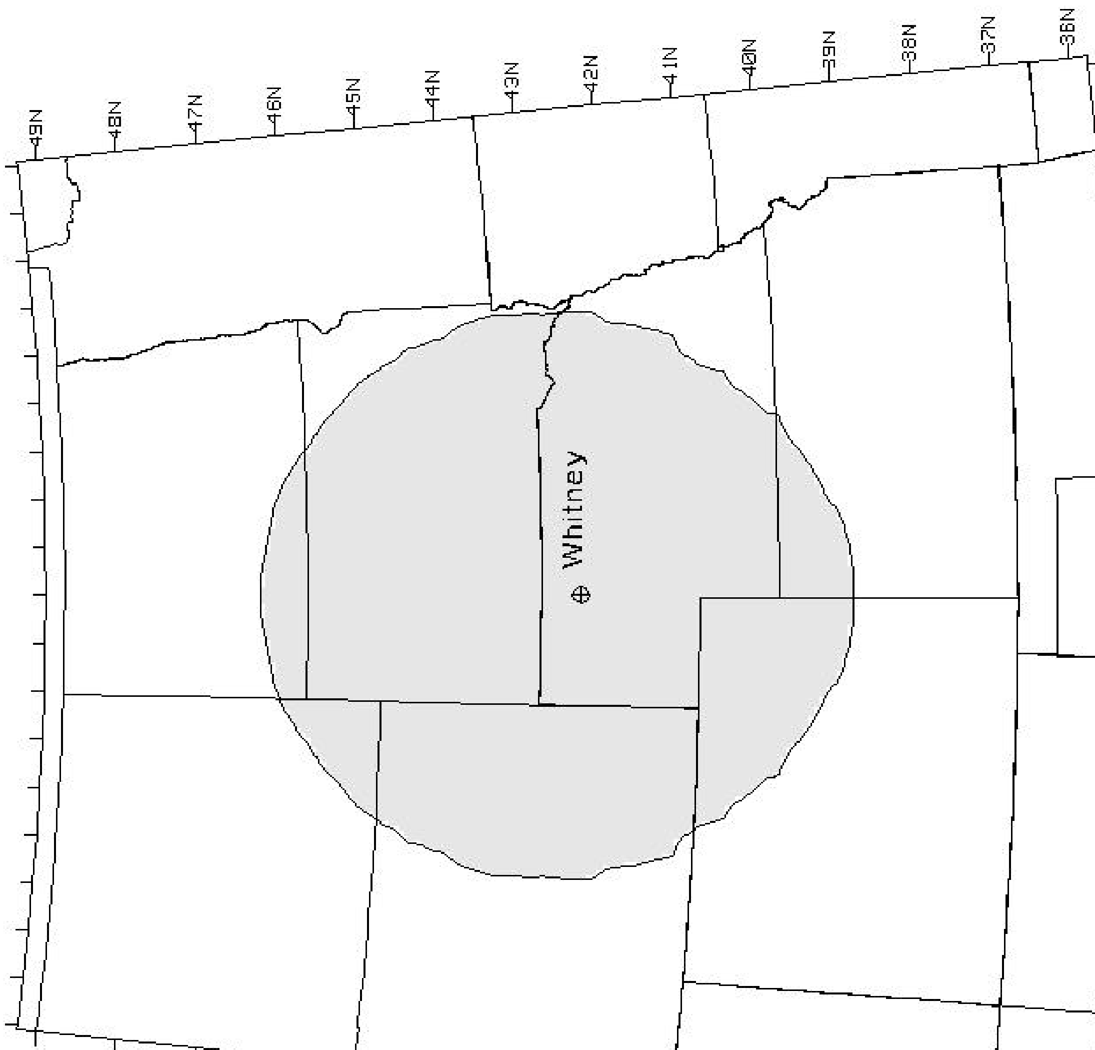


Figure 5.5. Whitney, NE.

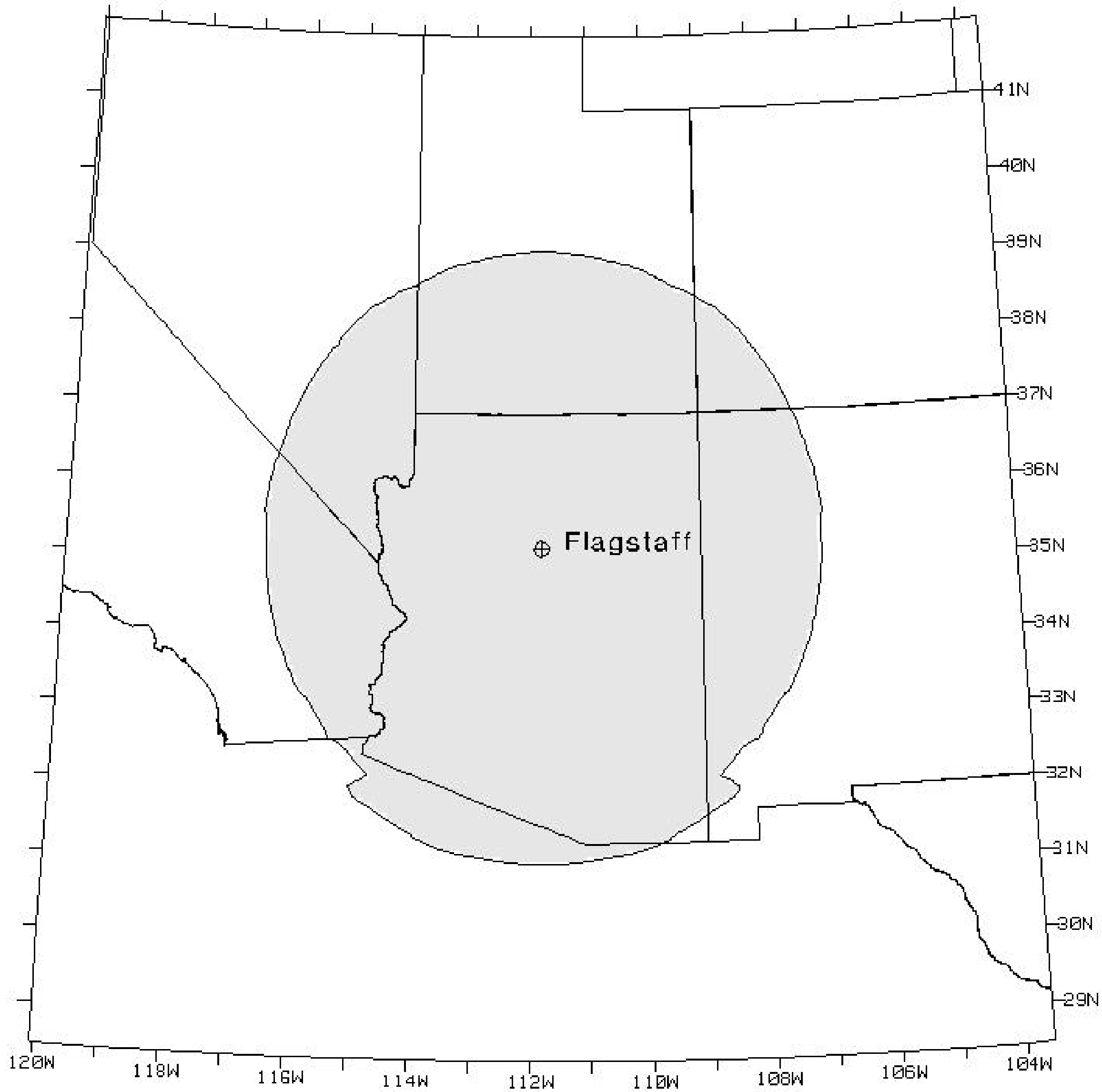


Figure 5.6. Flagstaff, AZ.

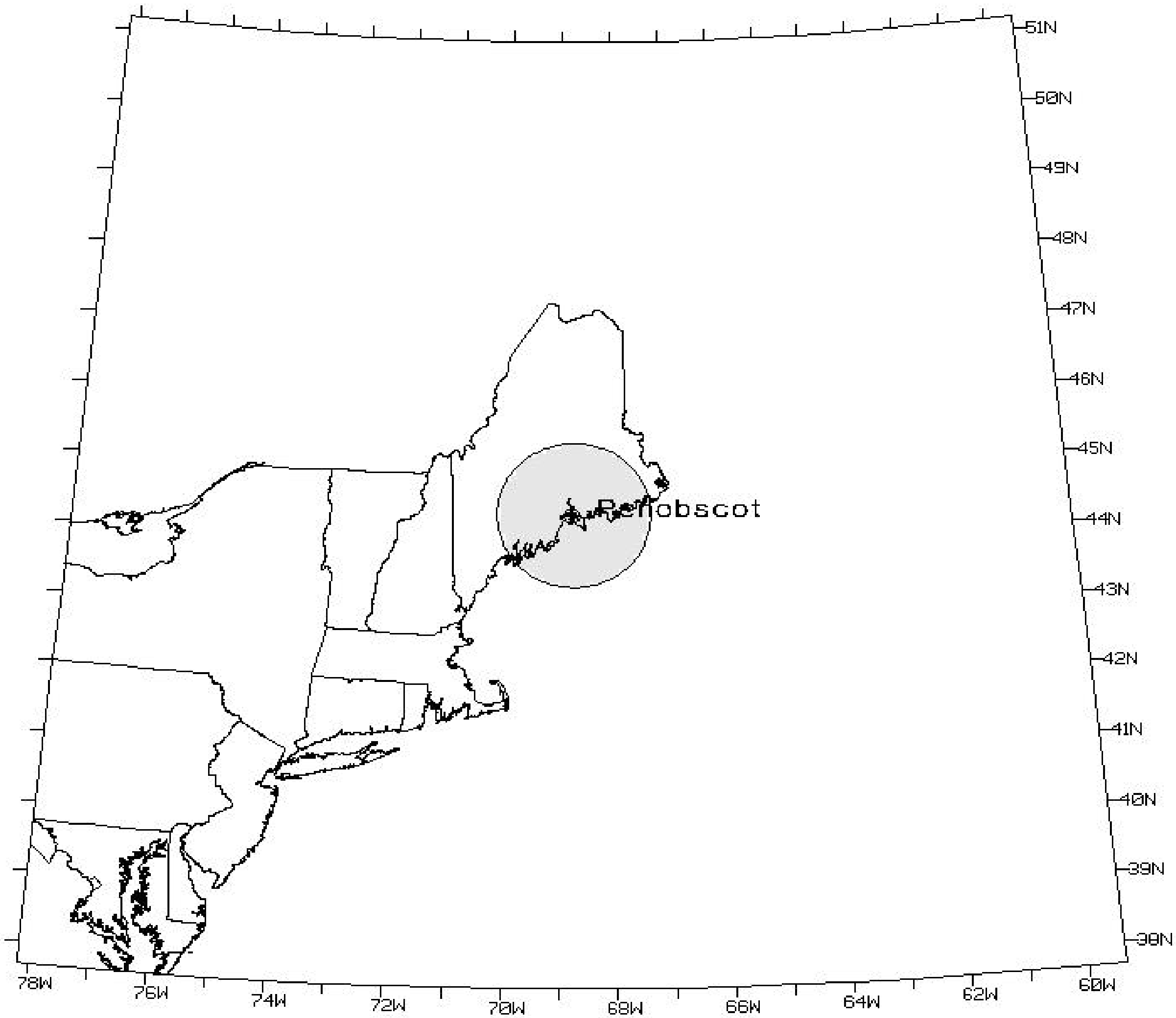


Figure 5.8. Penobscot, ME.

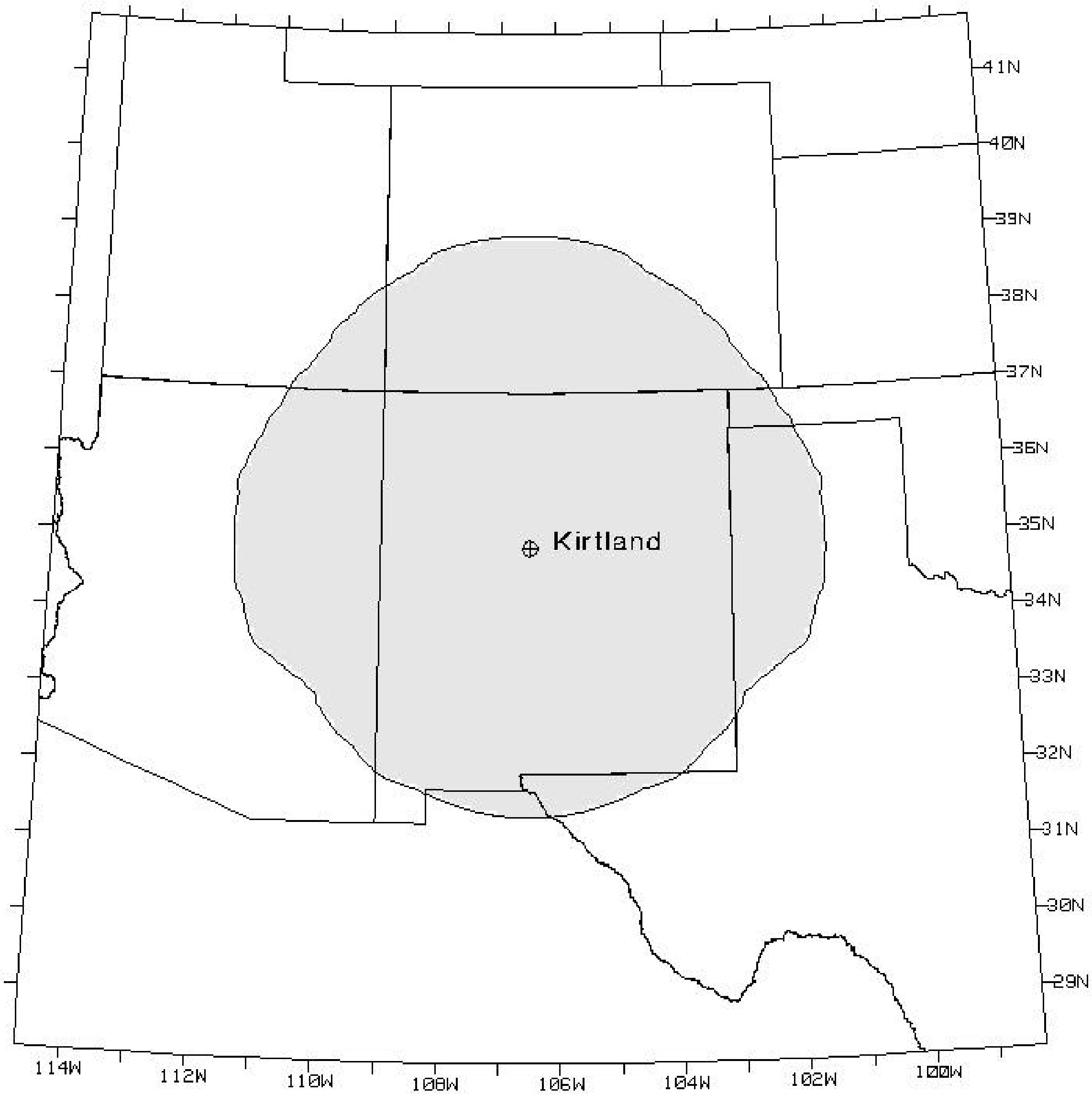


Figure 5.9. Kirtland, NM.

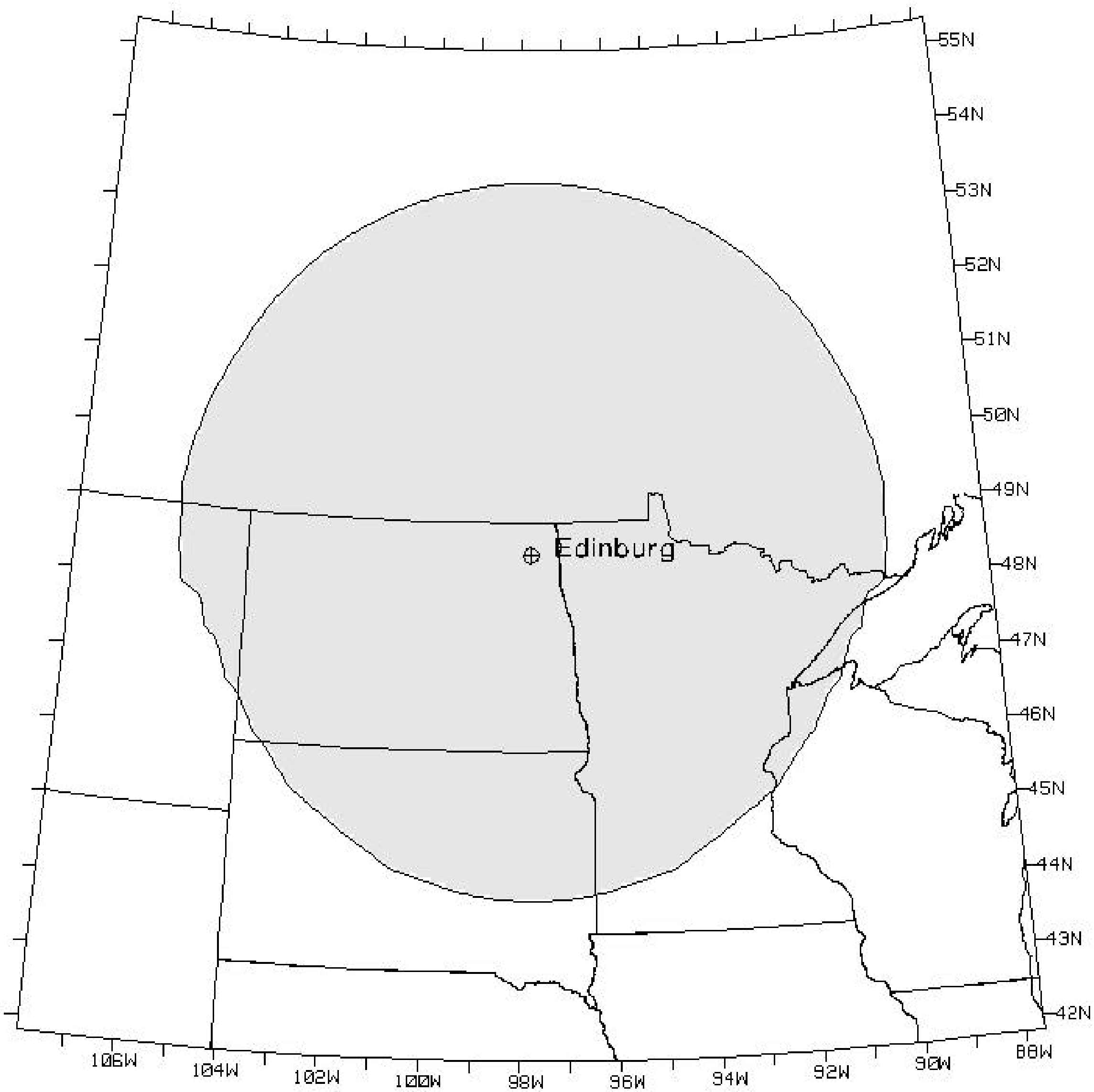


Figure 5.10. Edinburg, ND.

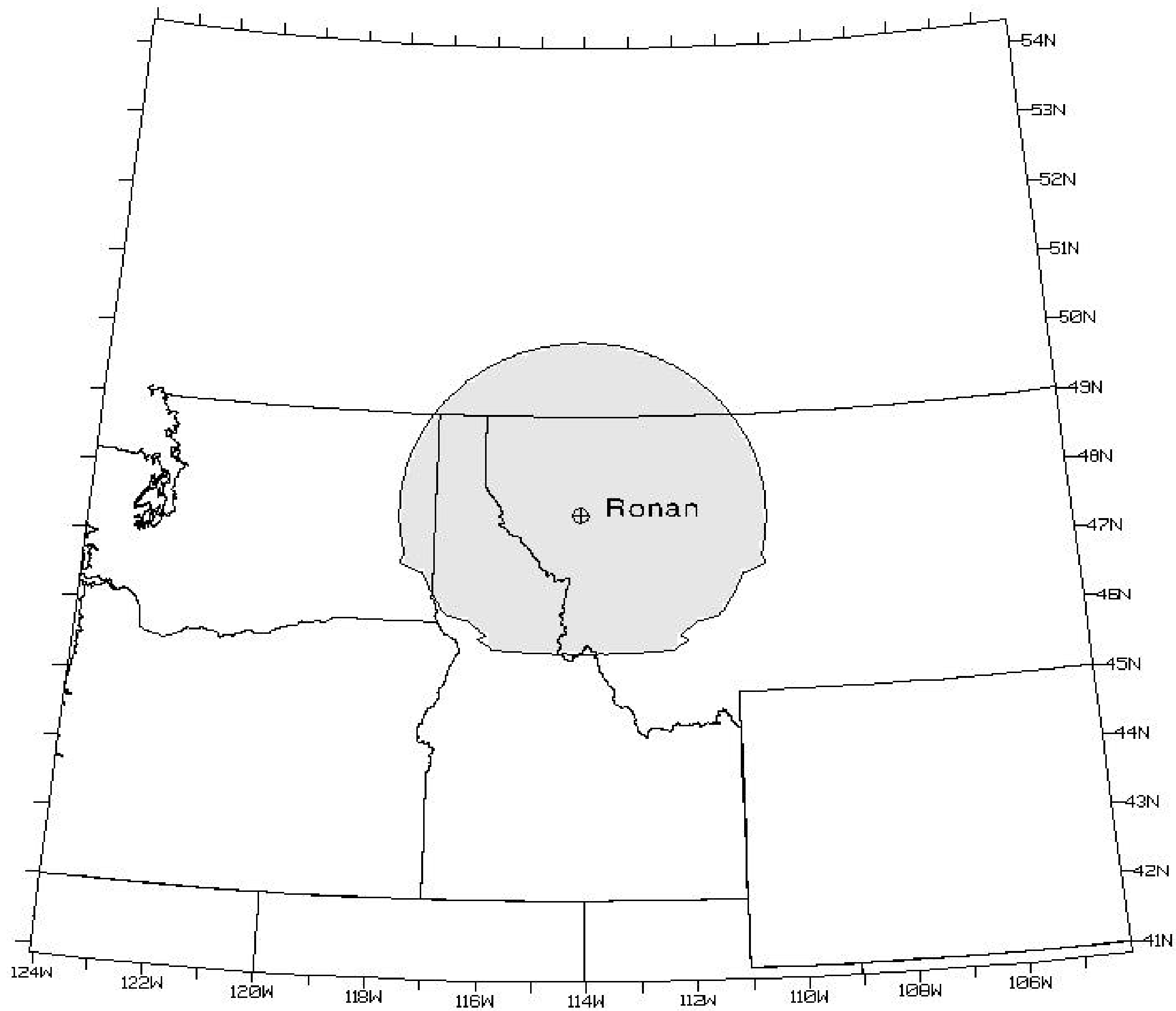


Figure 5.7. Ronan, MT.

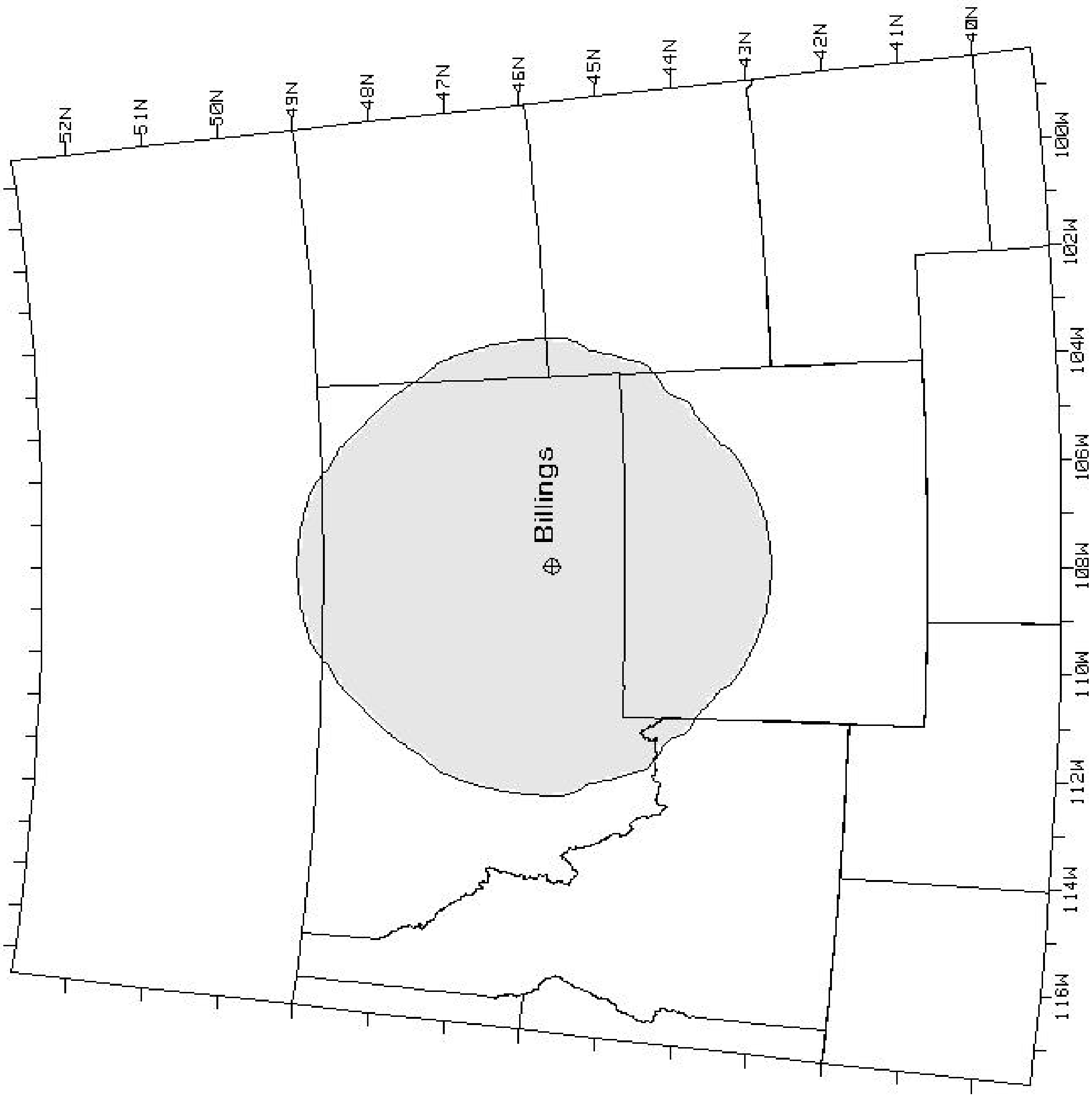


Figure 5.11. Billings, MT.

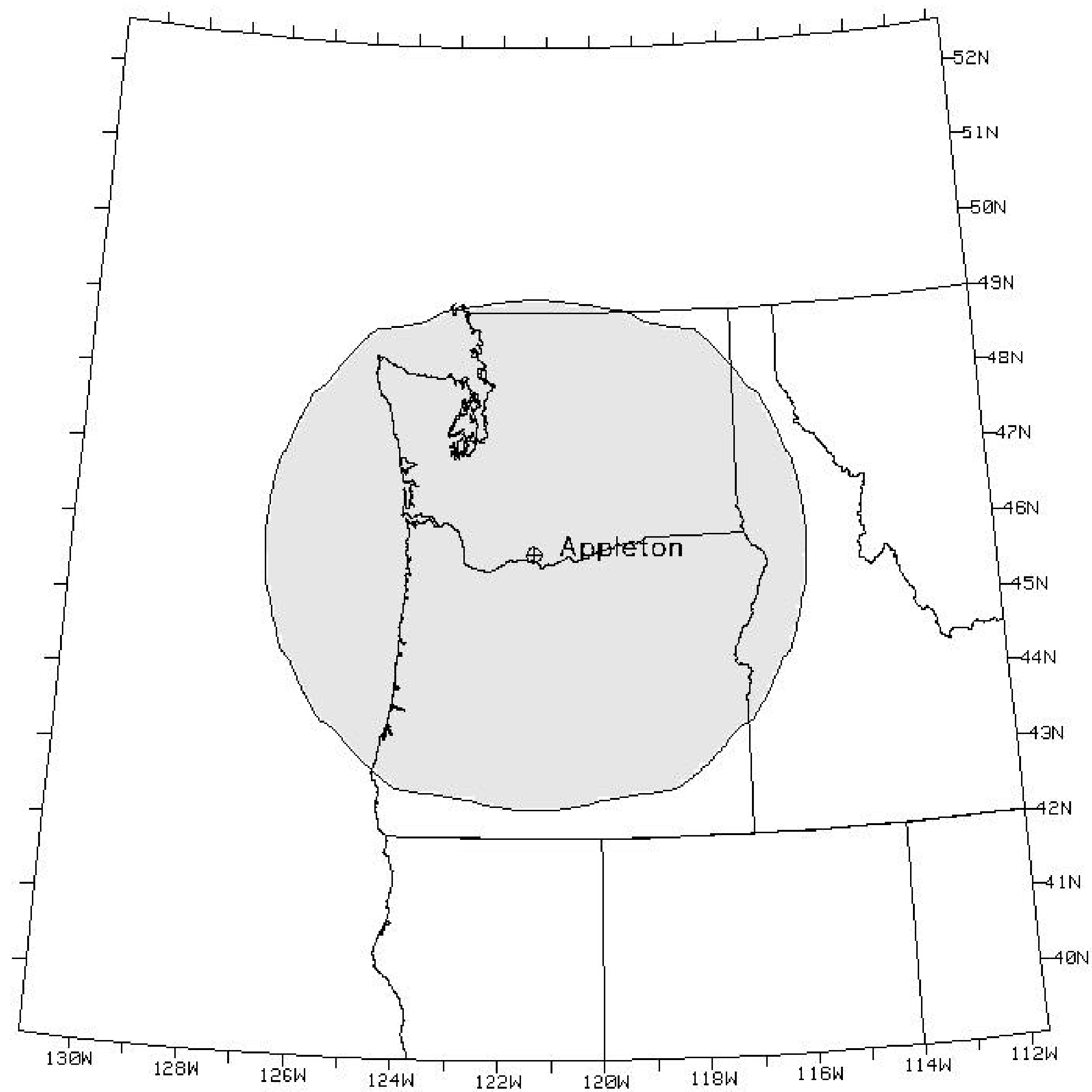
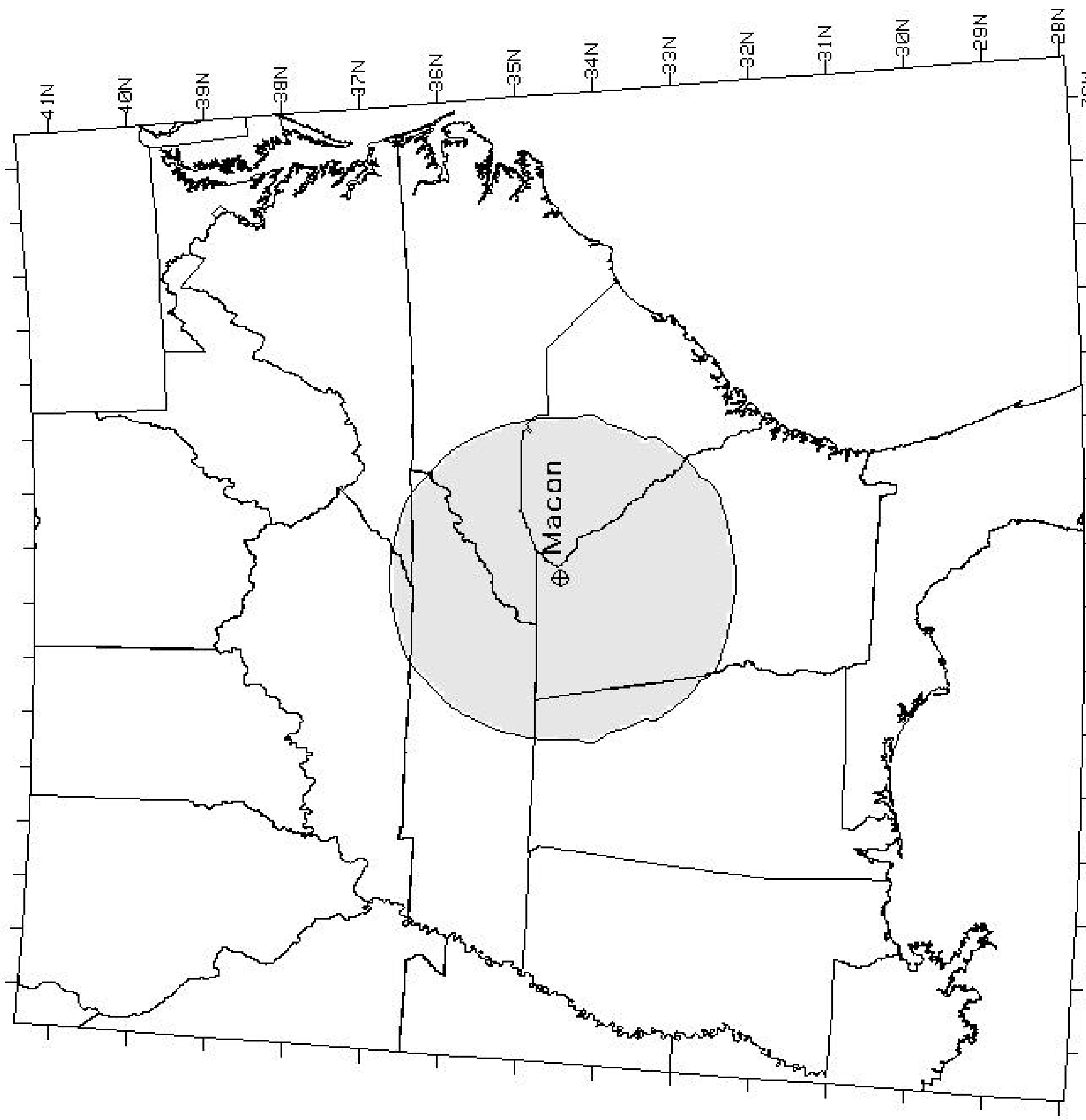


Figure 5.12. Appleton, WA.



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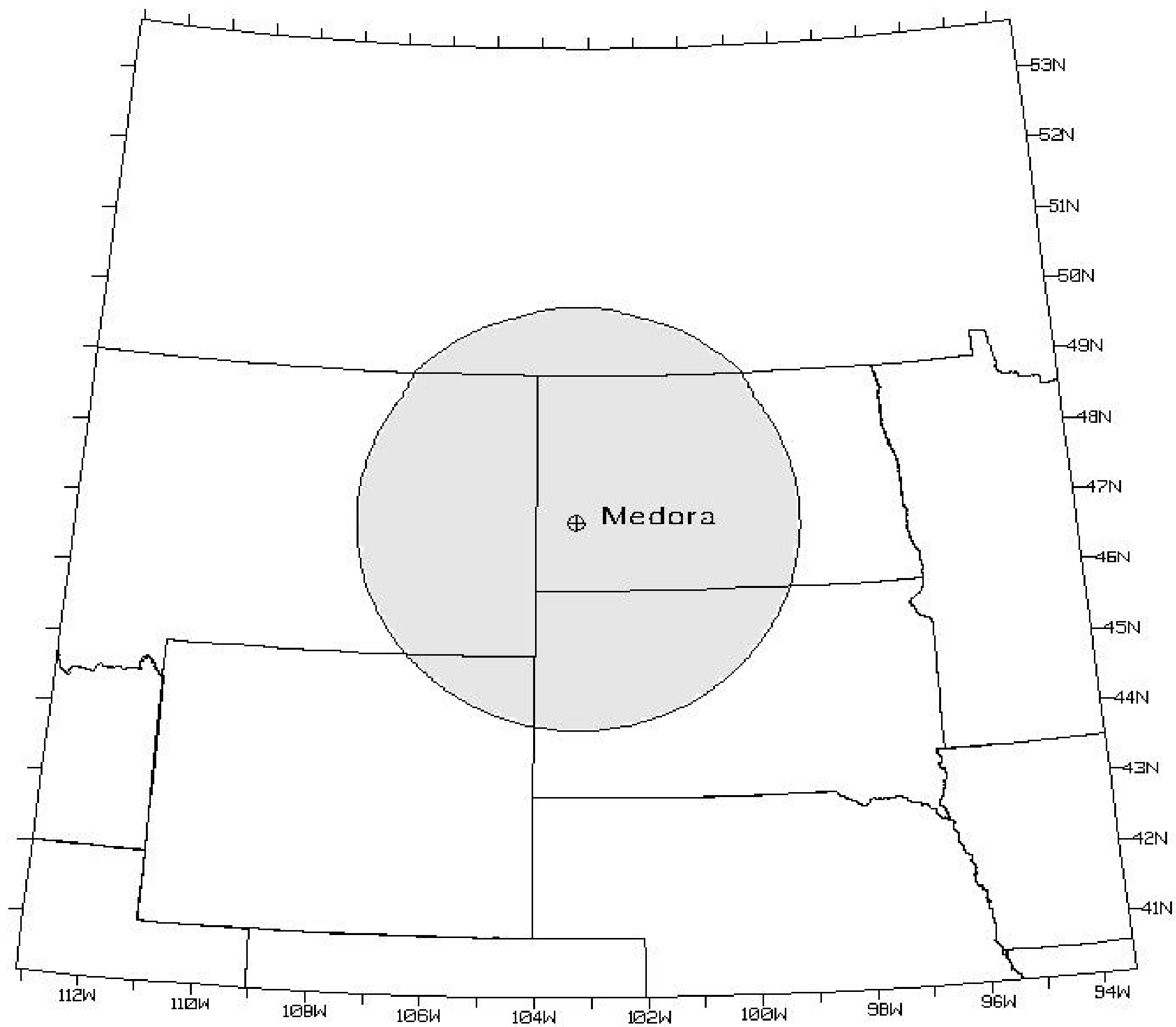

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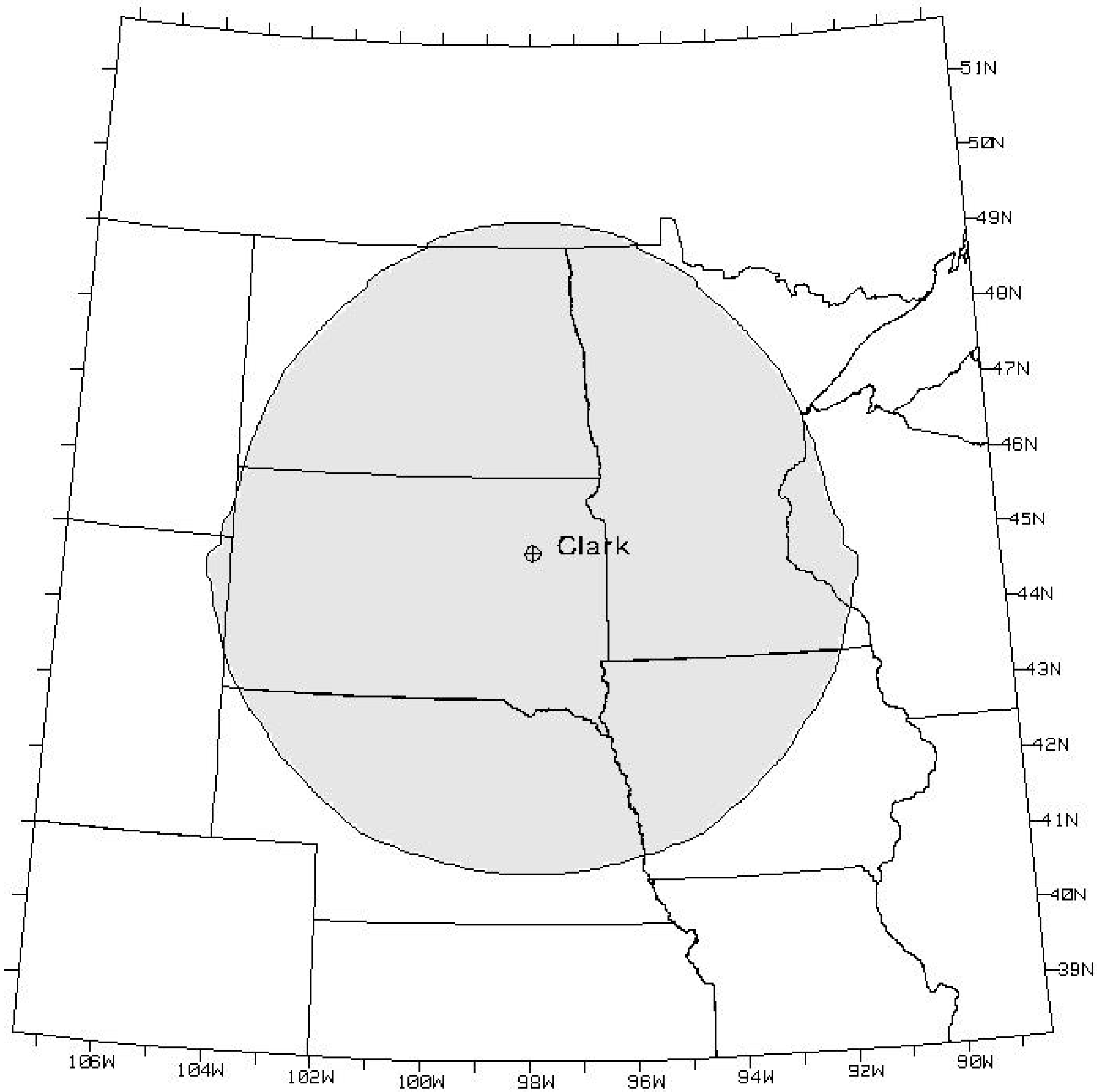

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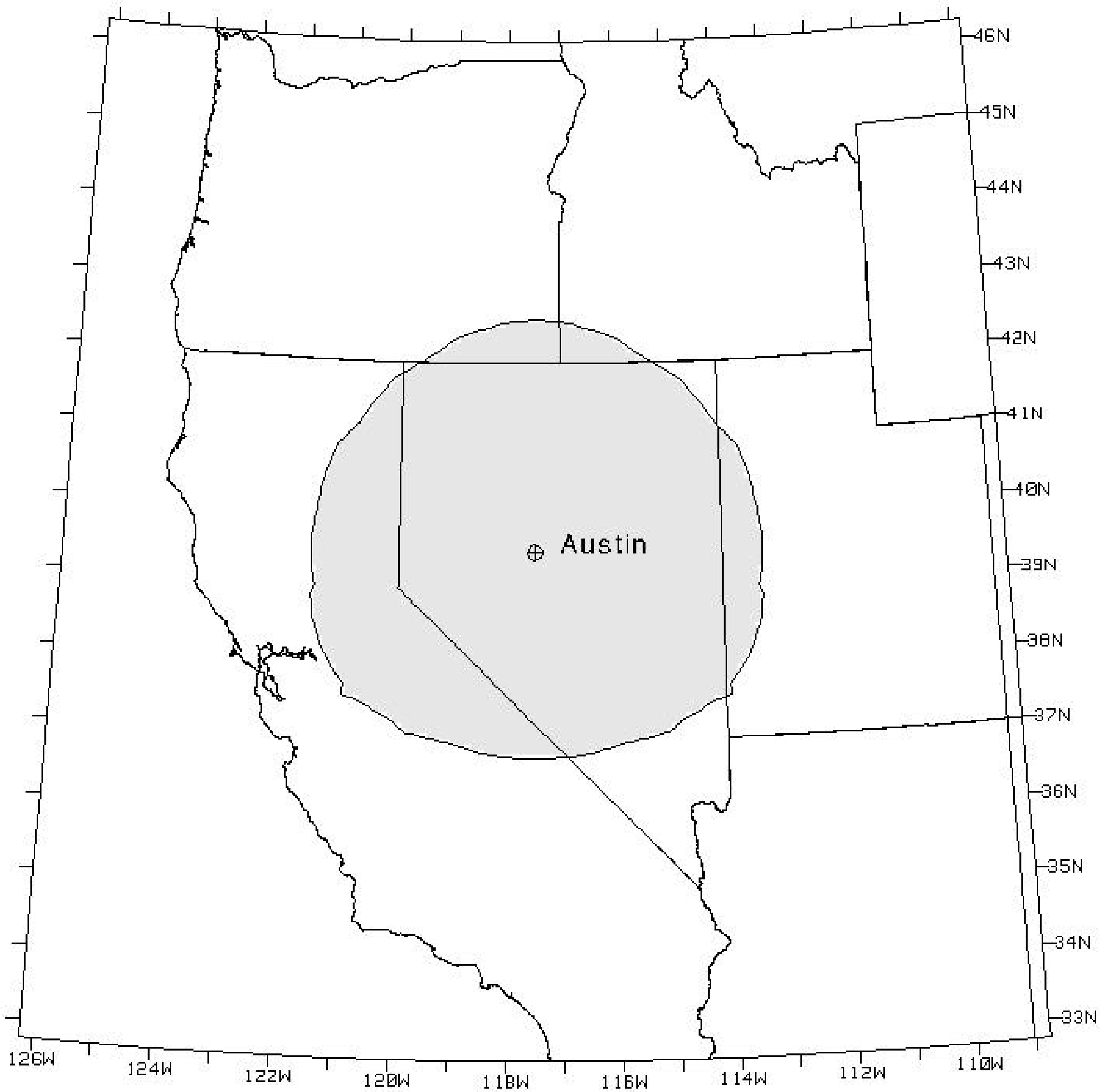


Figure 5.16. Austin, NV.

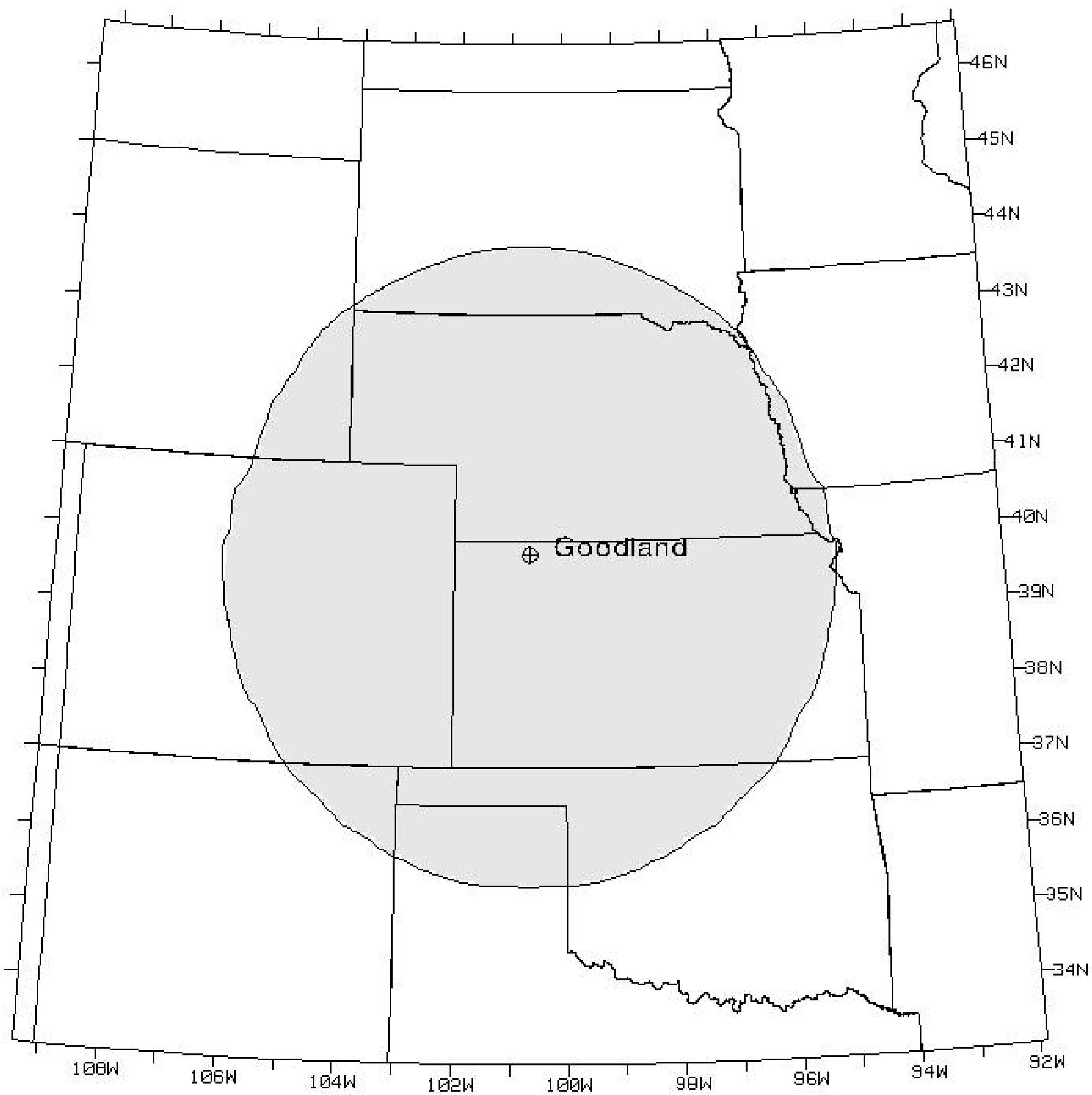
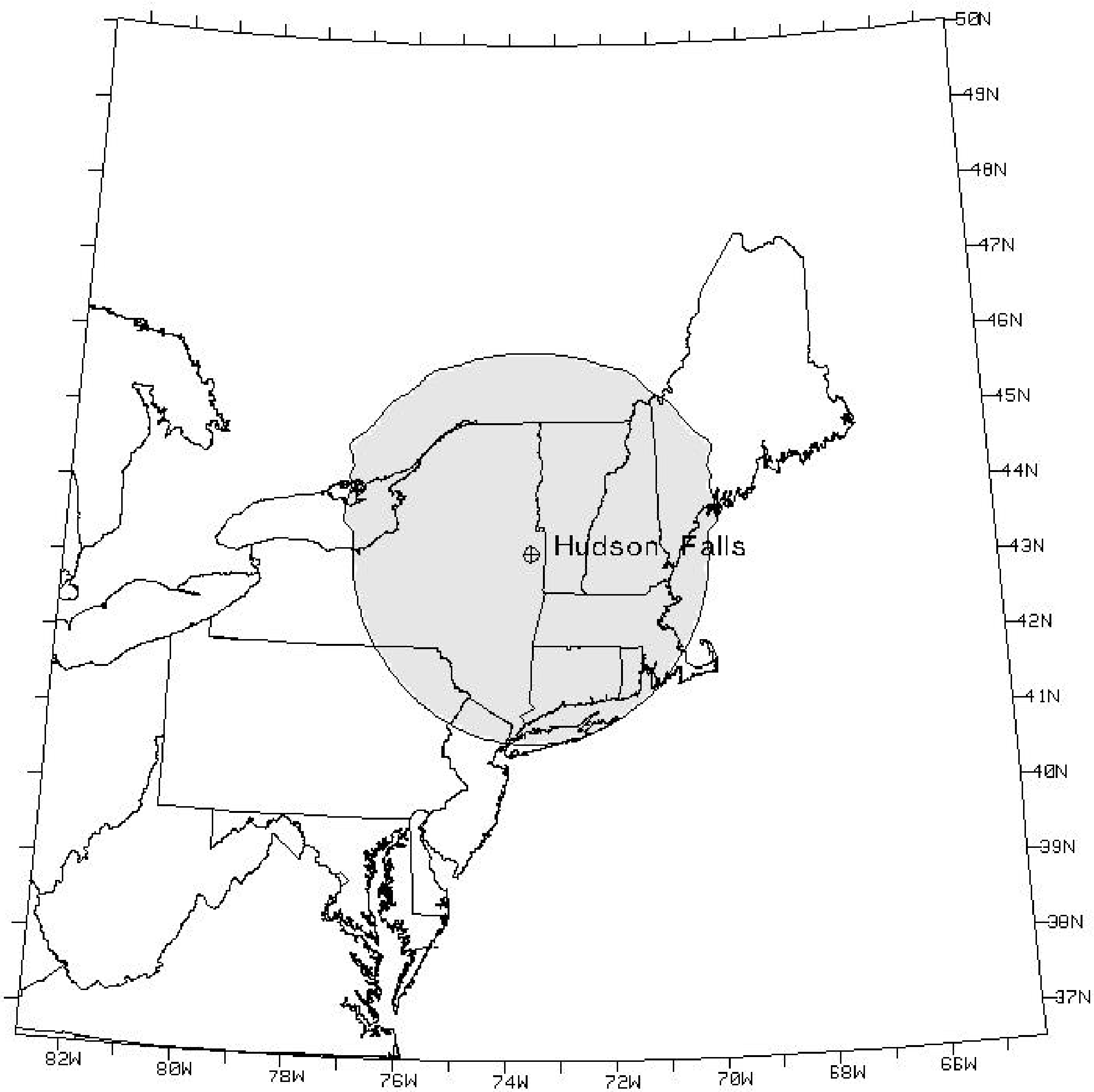


Figure 5.17. Goodland, KS.



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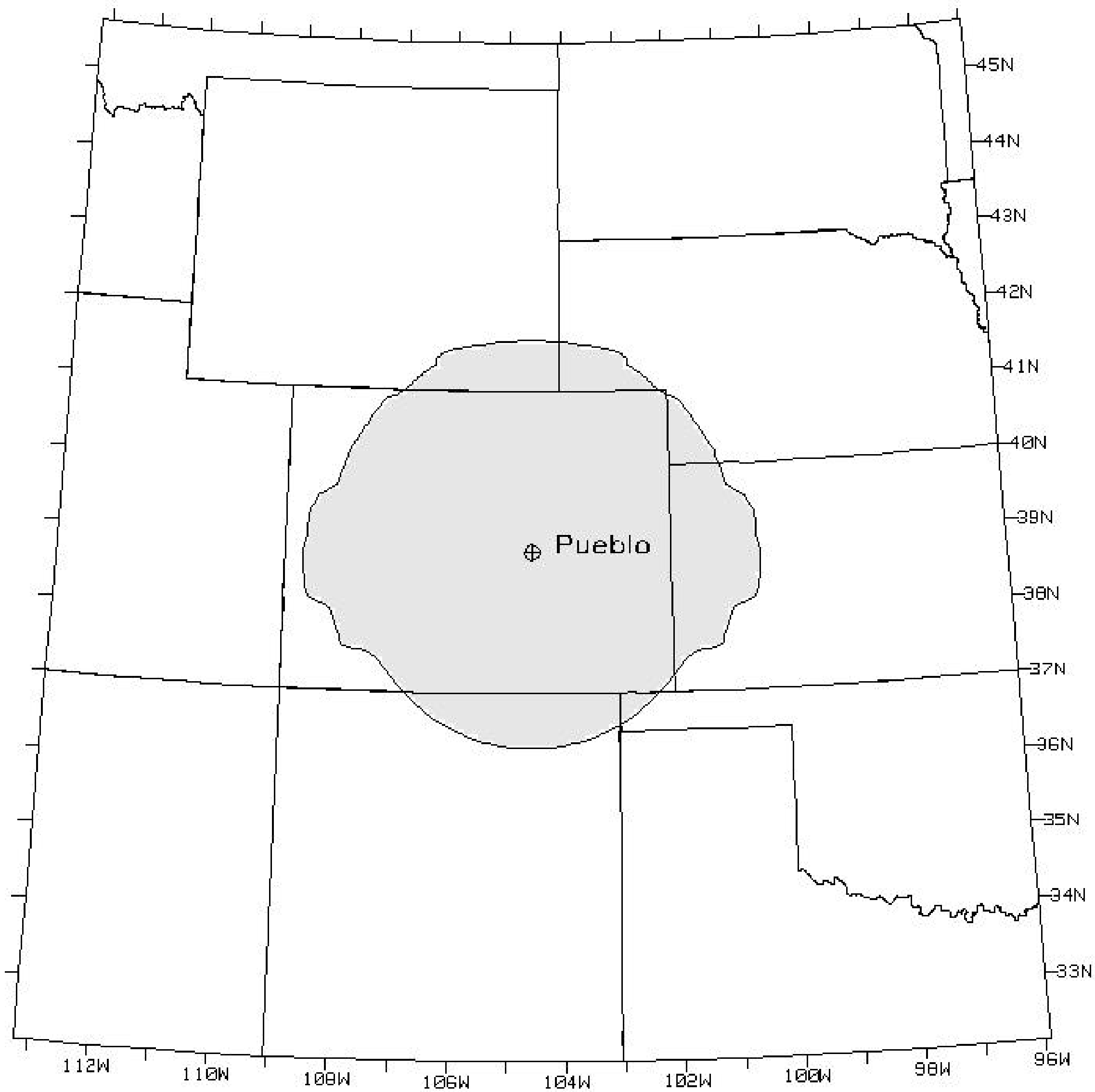

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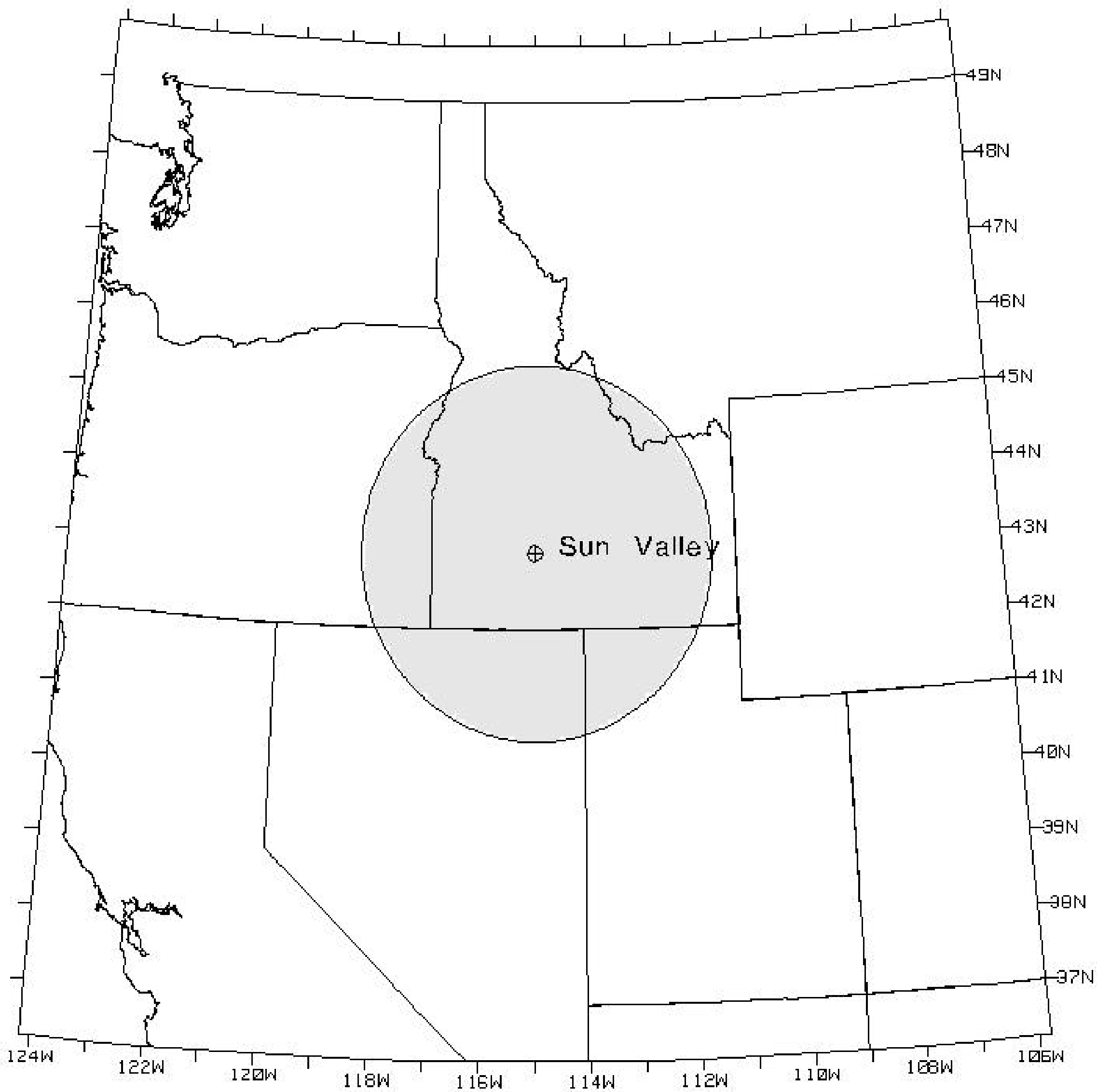

Figure 5.20. Sun Valley, ID.

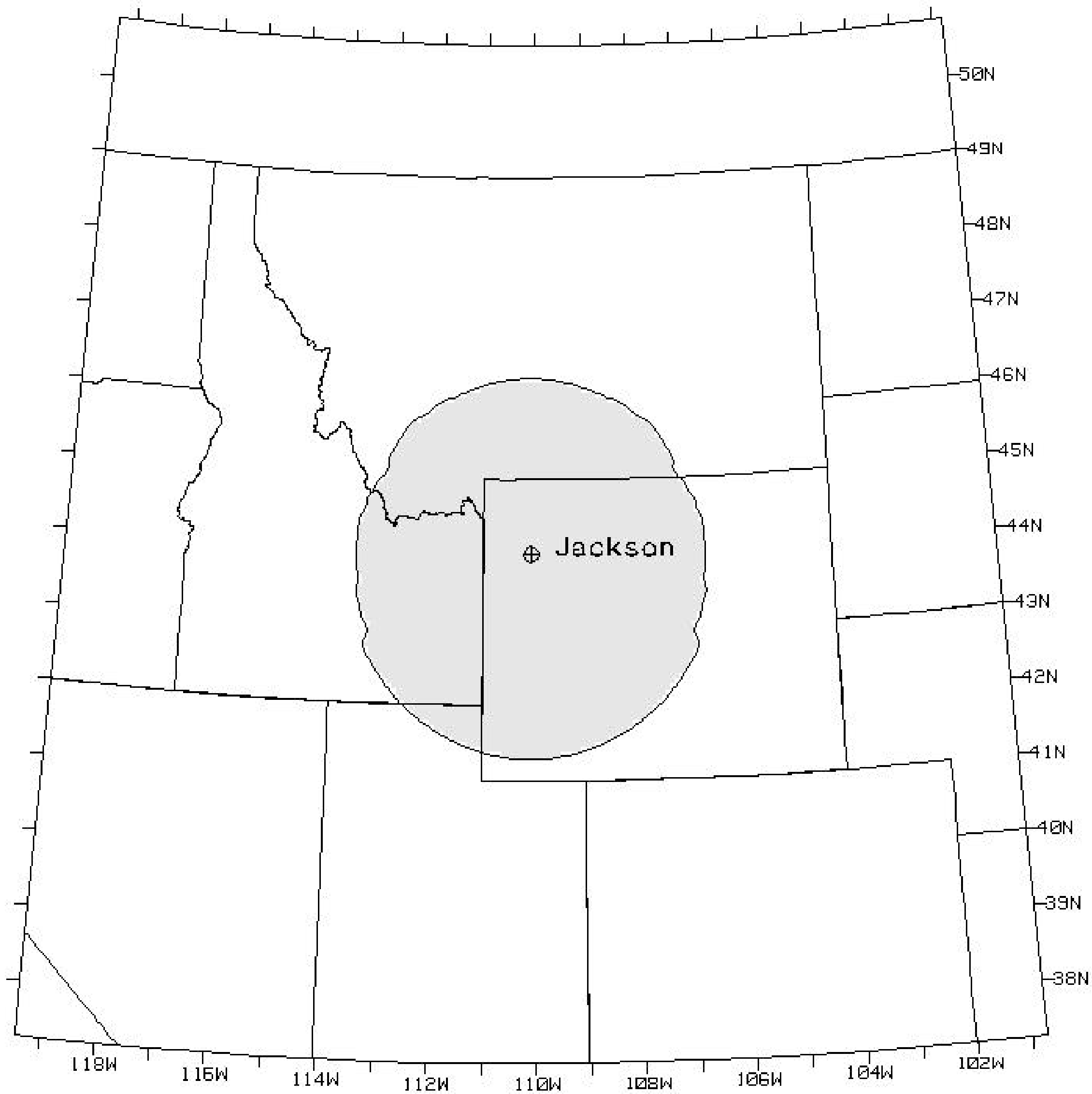

Figure 5.21. Jackson, WY.

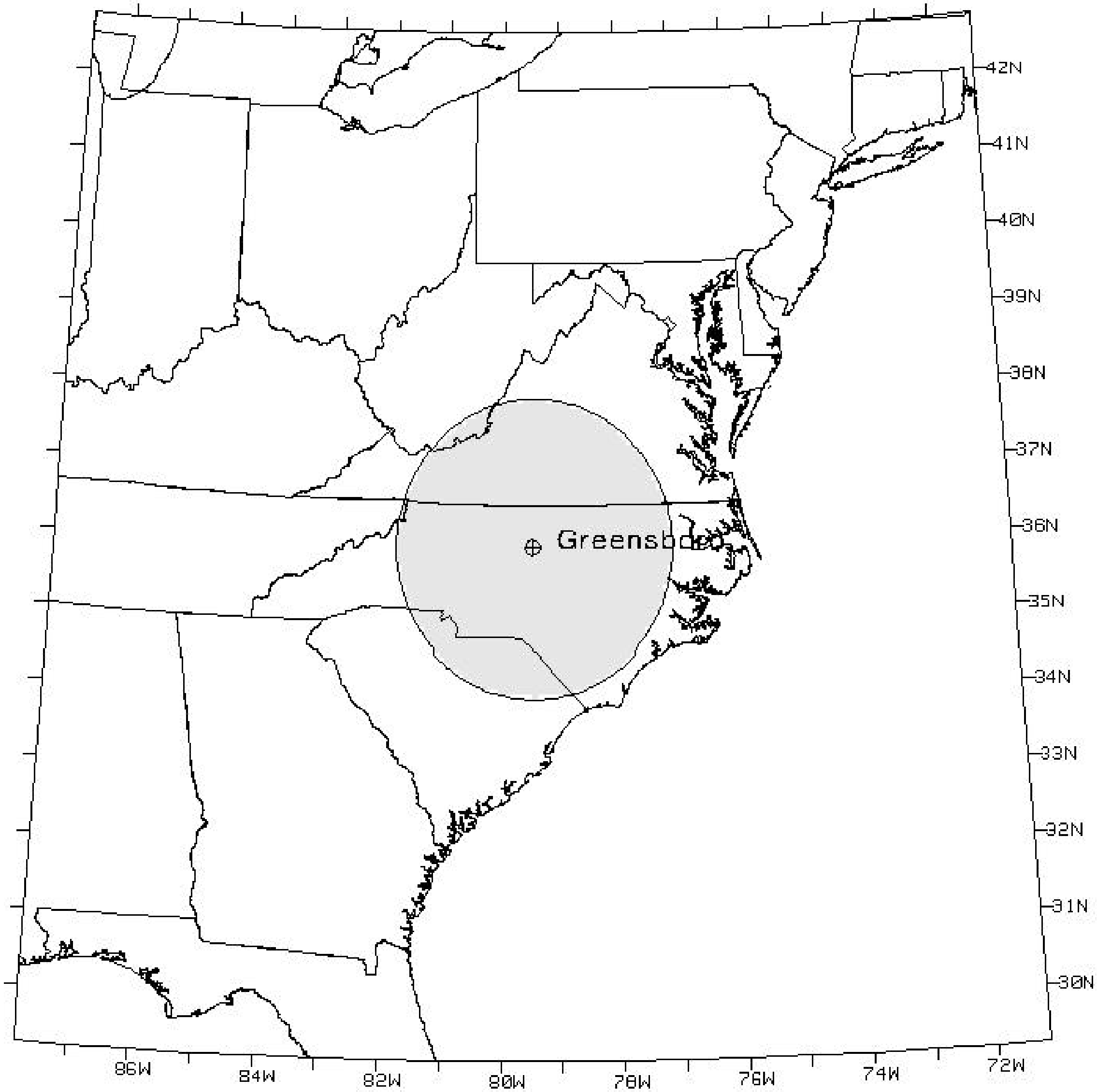

Figure 5.22. Greensboro, NC.

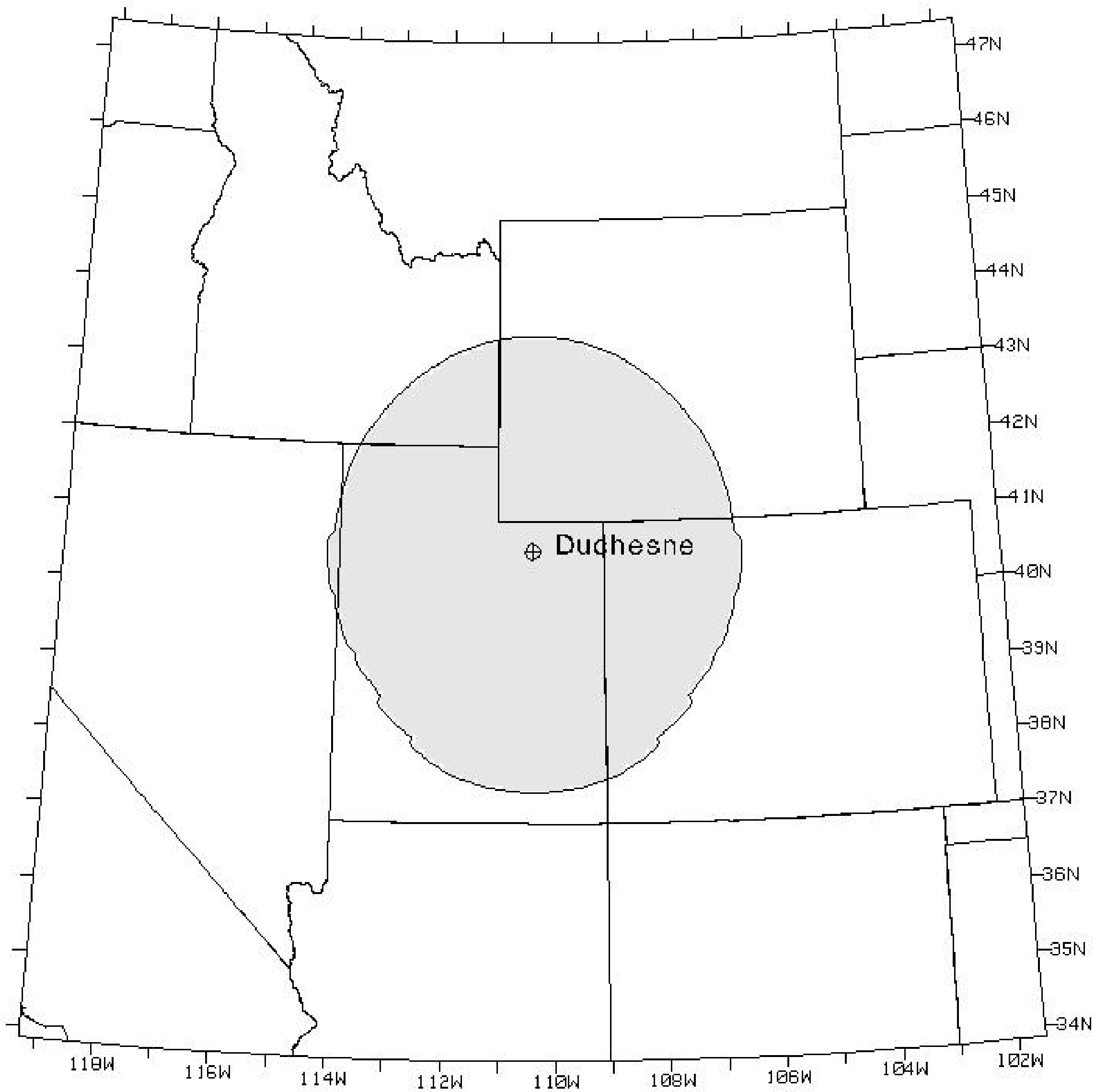

Figure 5.23. Duchesne, UT.

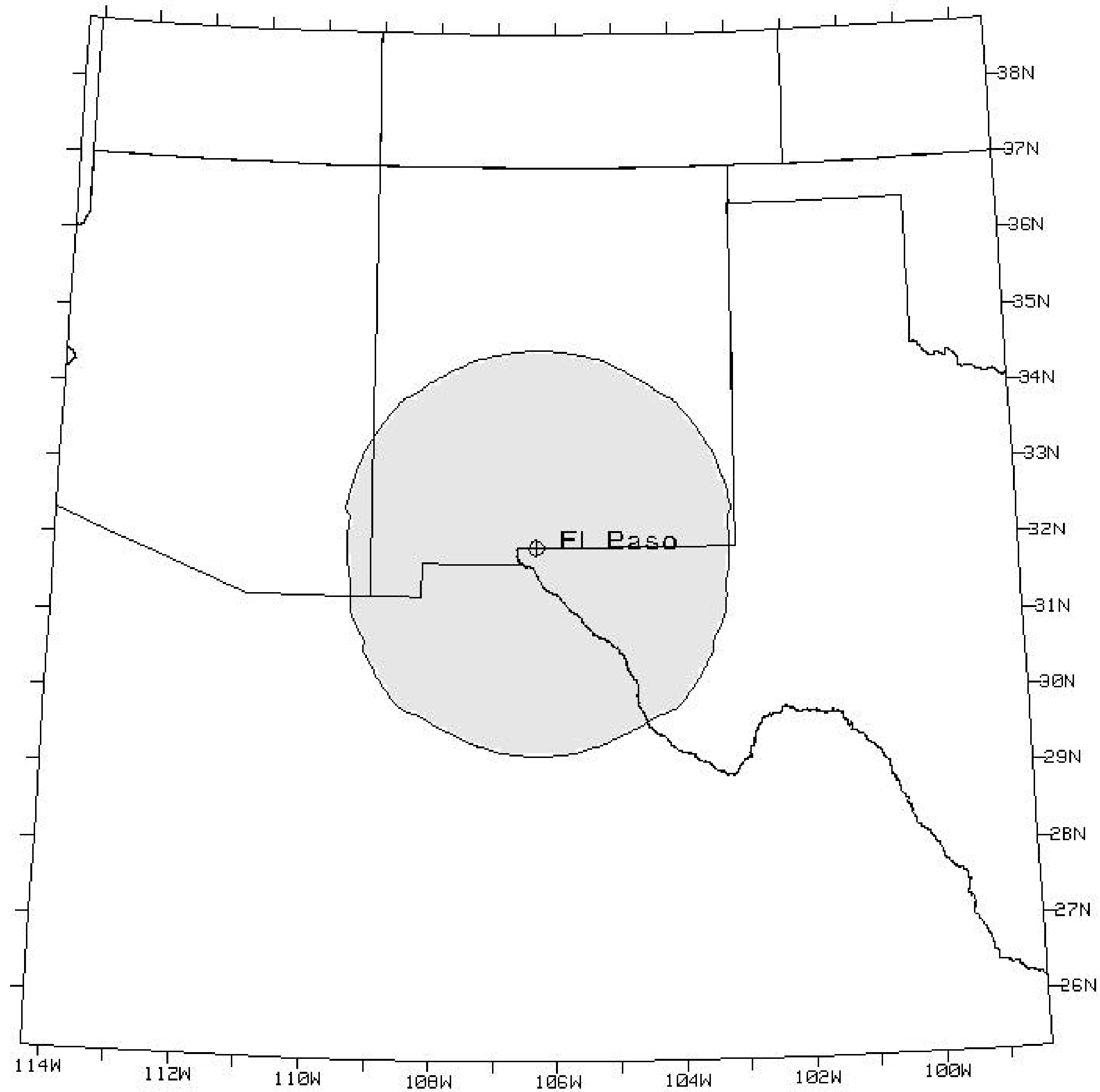

Figure 5.24. El Paso, TX.

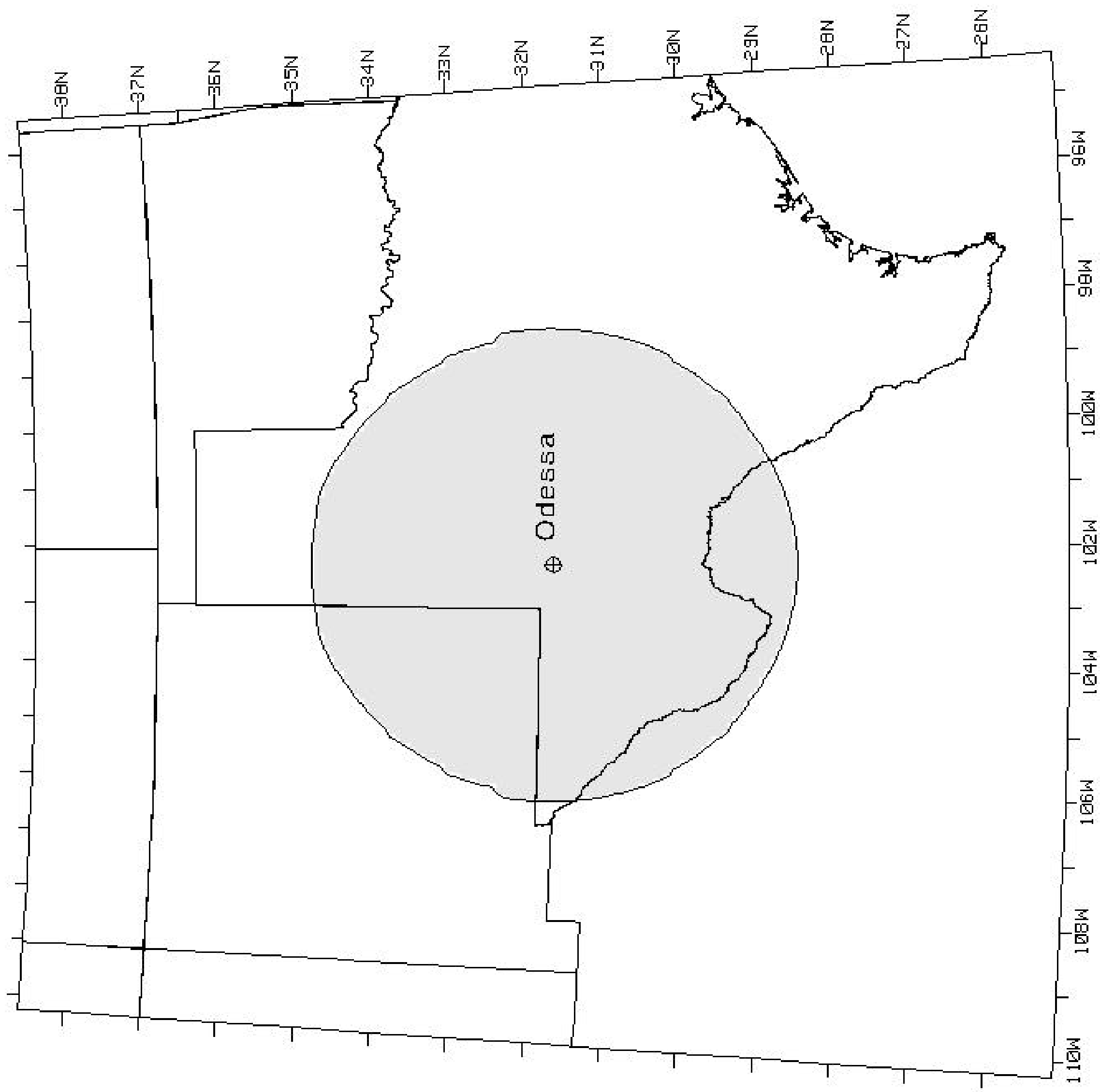

Figure 5.25. Odessa, TX.

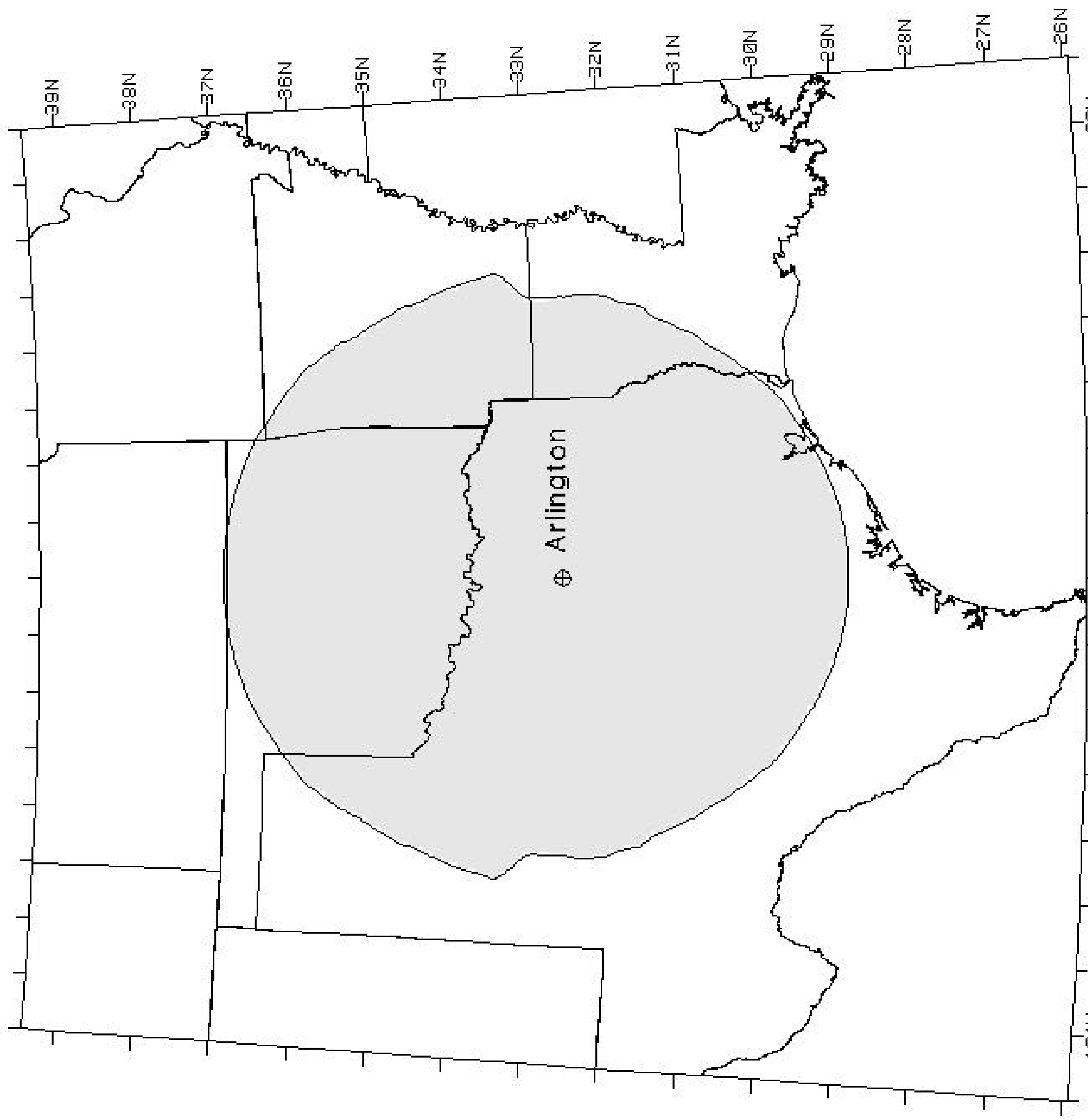

Figure 5.26. Arlington, TX.

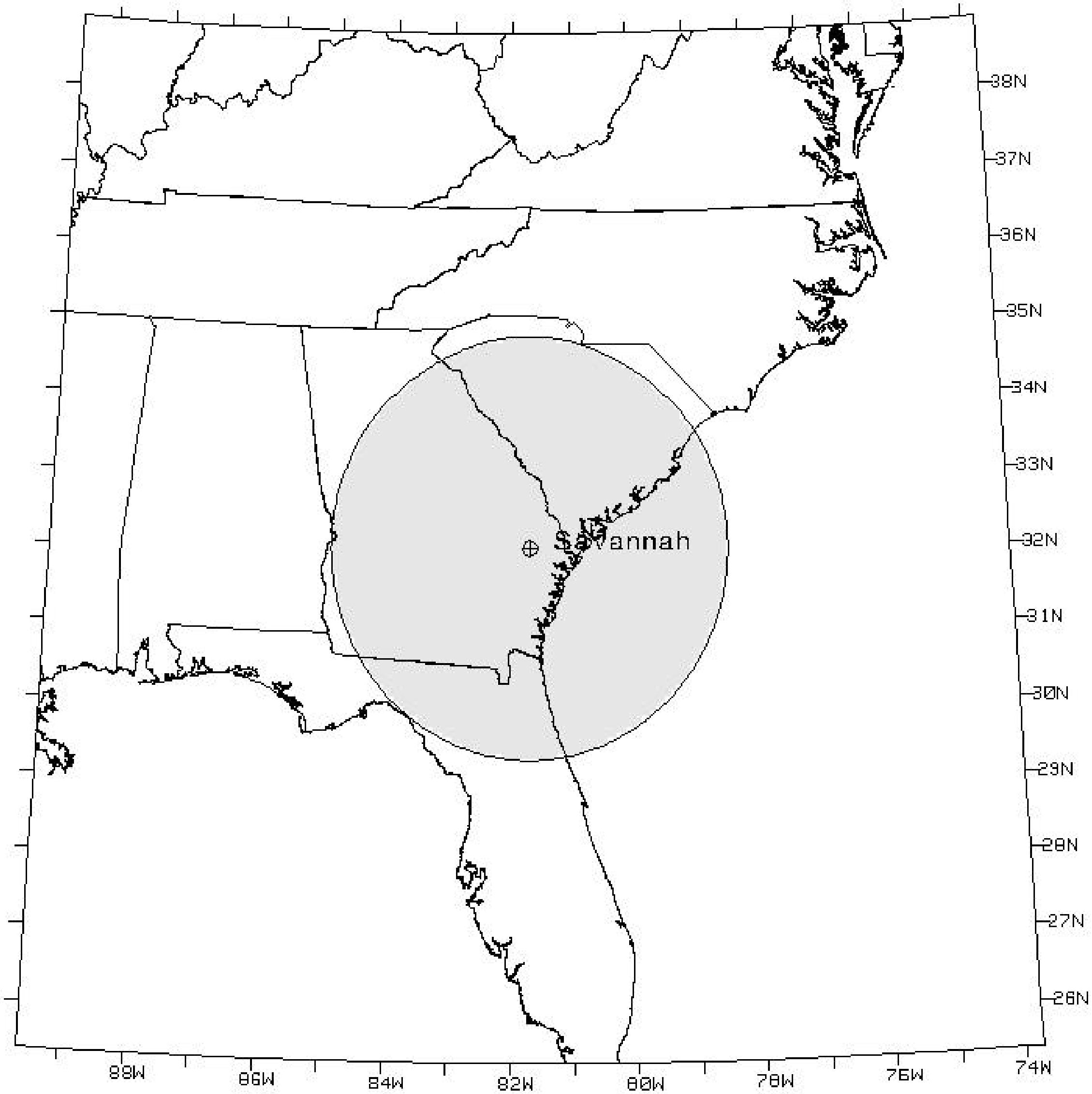

Figure 5.27. Savannah, GA.

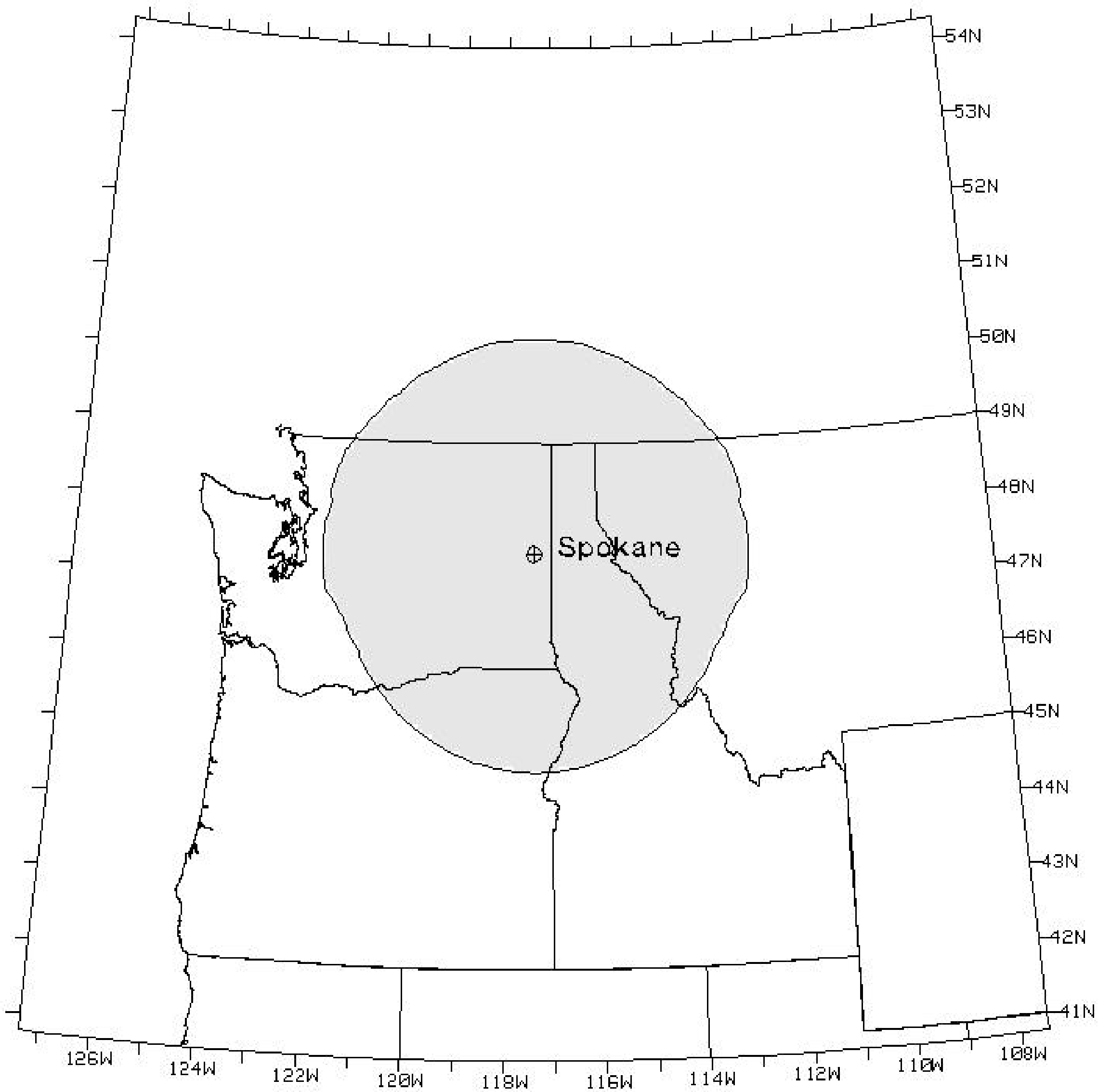

Figure 5.28. Spokane, WA.

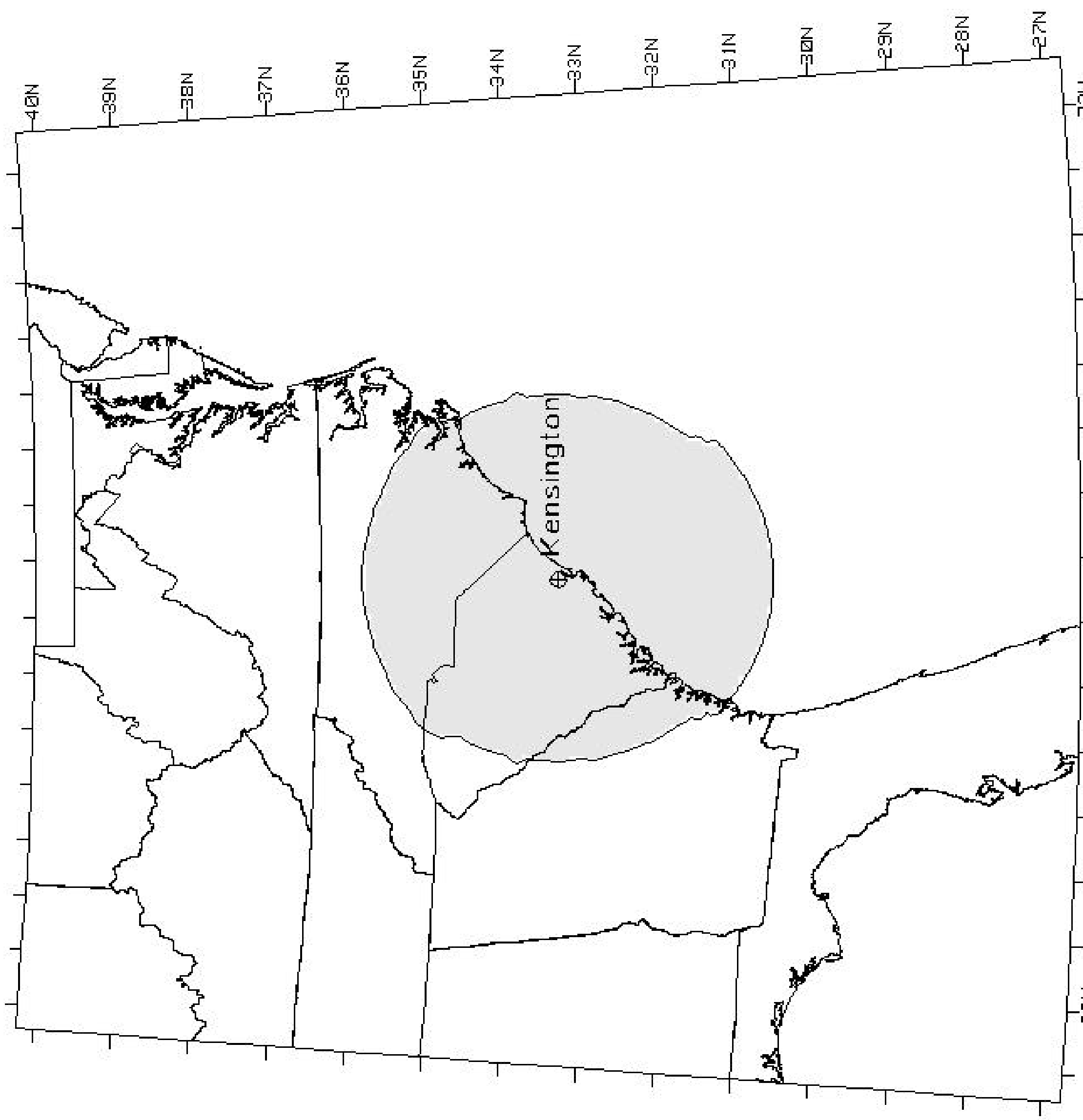

Figure 5.29. Kensington, SC.

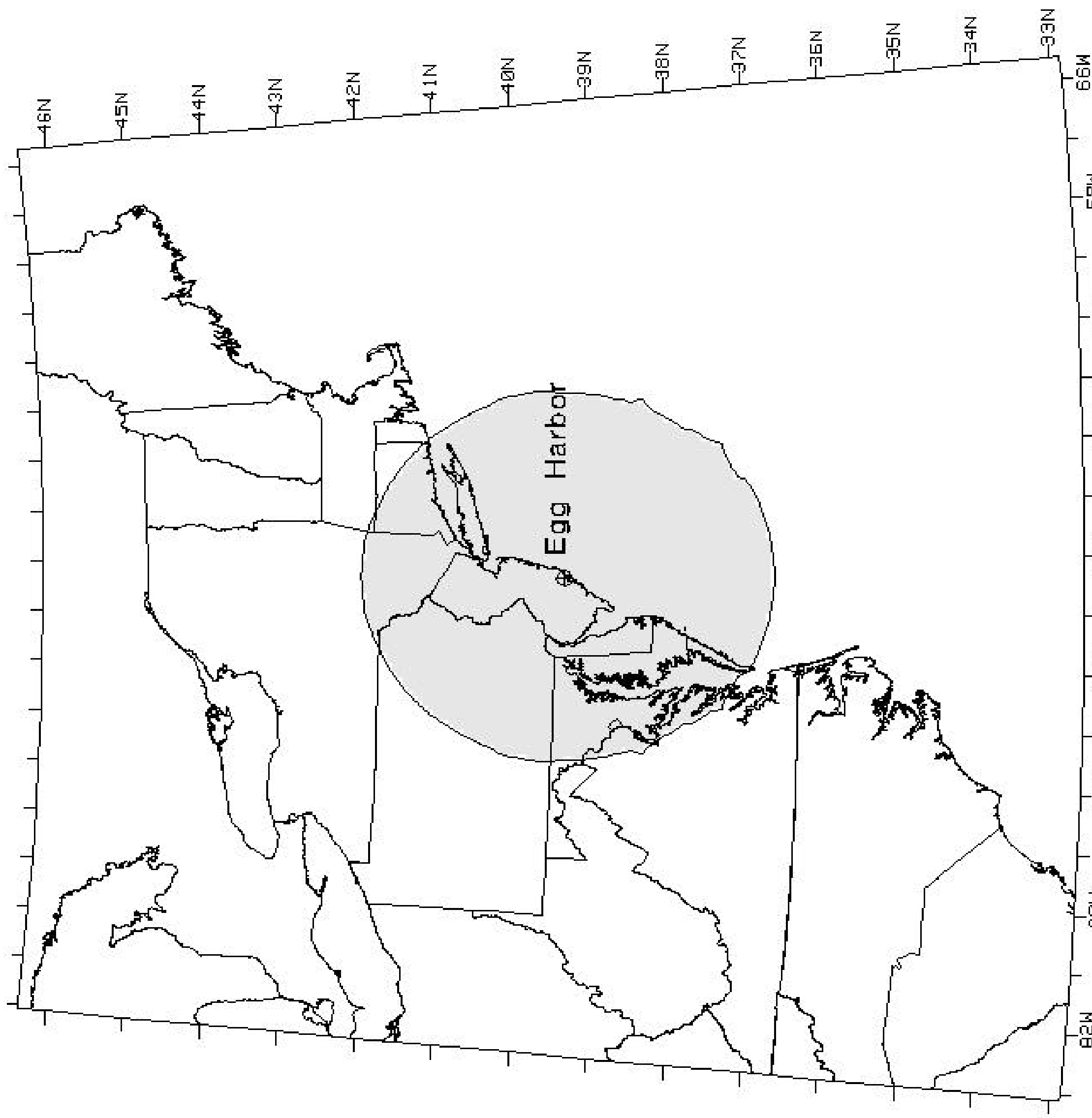

Figure 5.30. Egg Harbor, NJ.

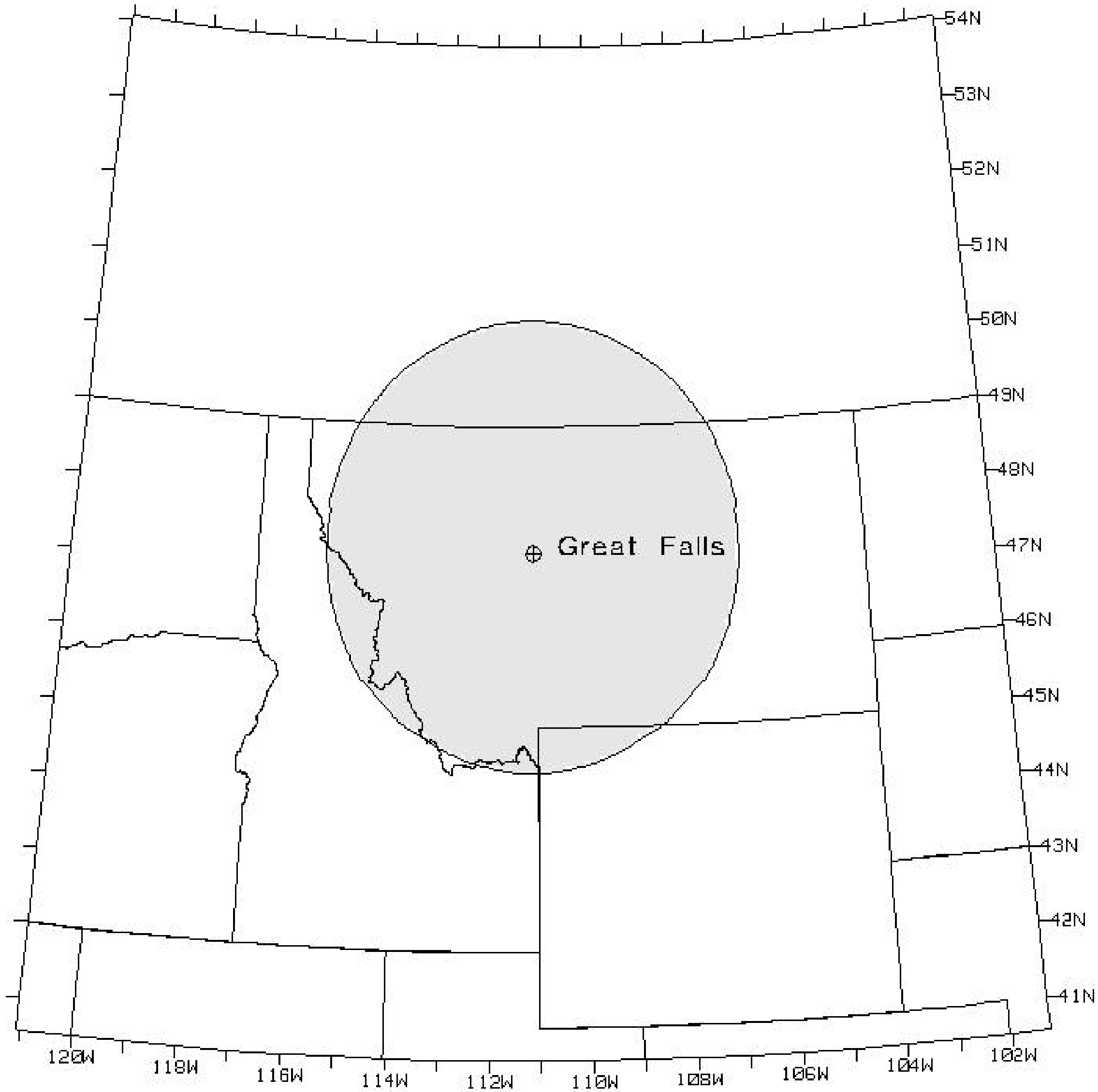

Figure 5.31. Great Falls, MT.

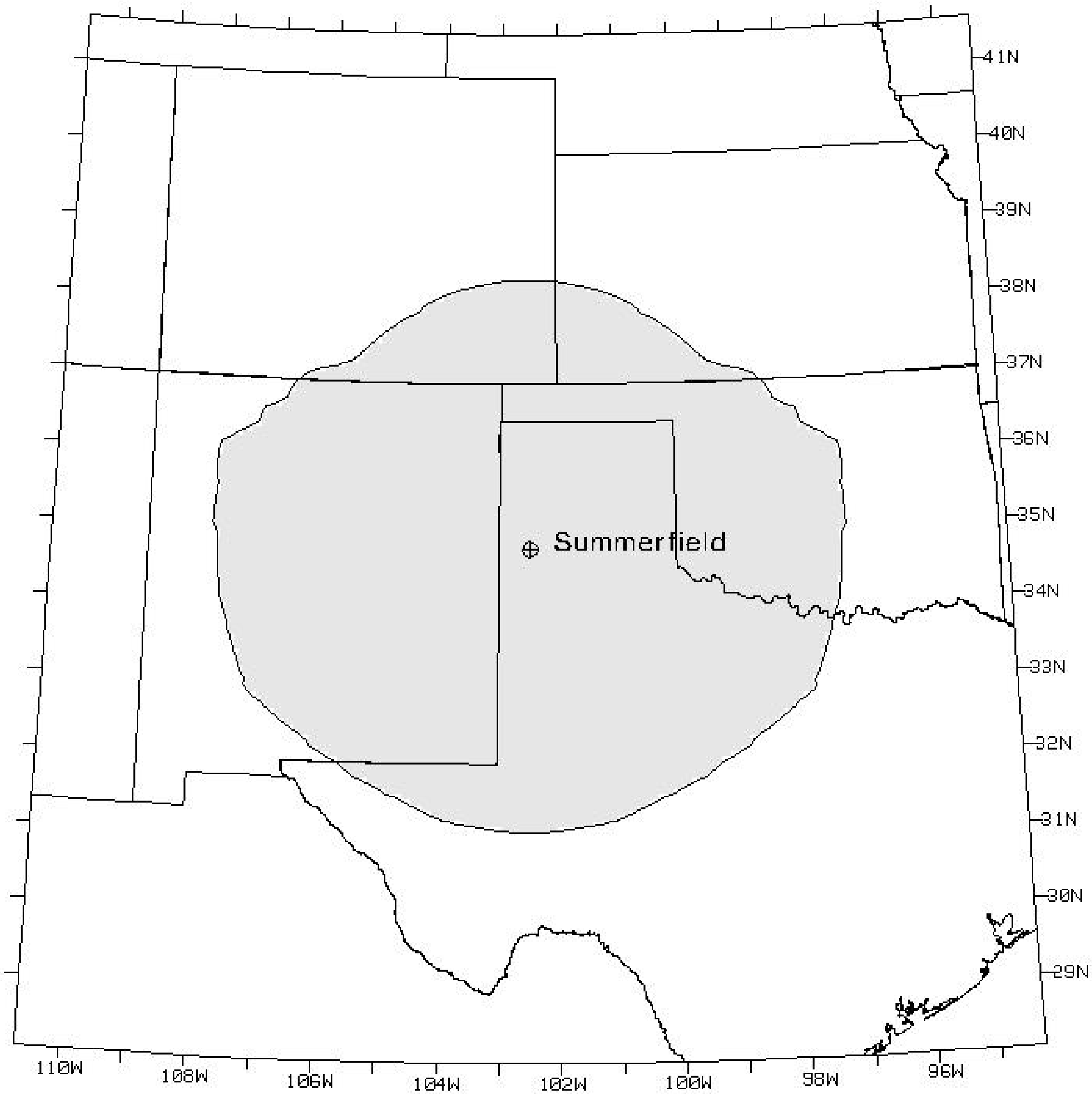

Figure 5.32. Summerfield, TX.

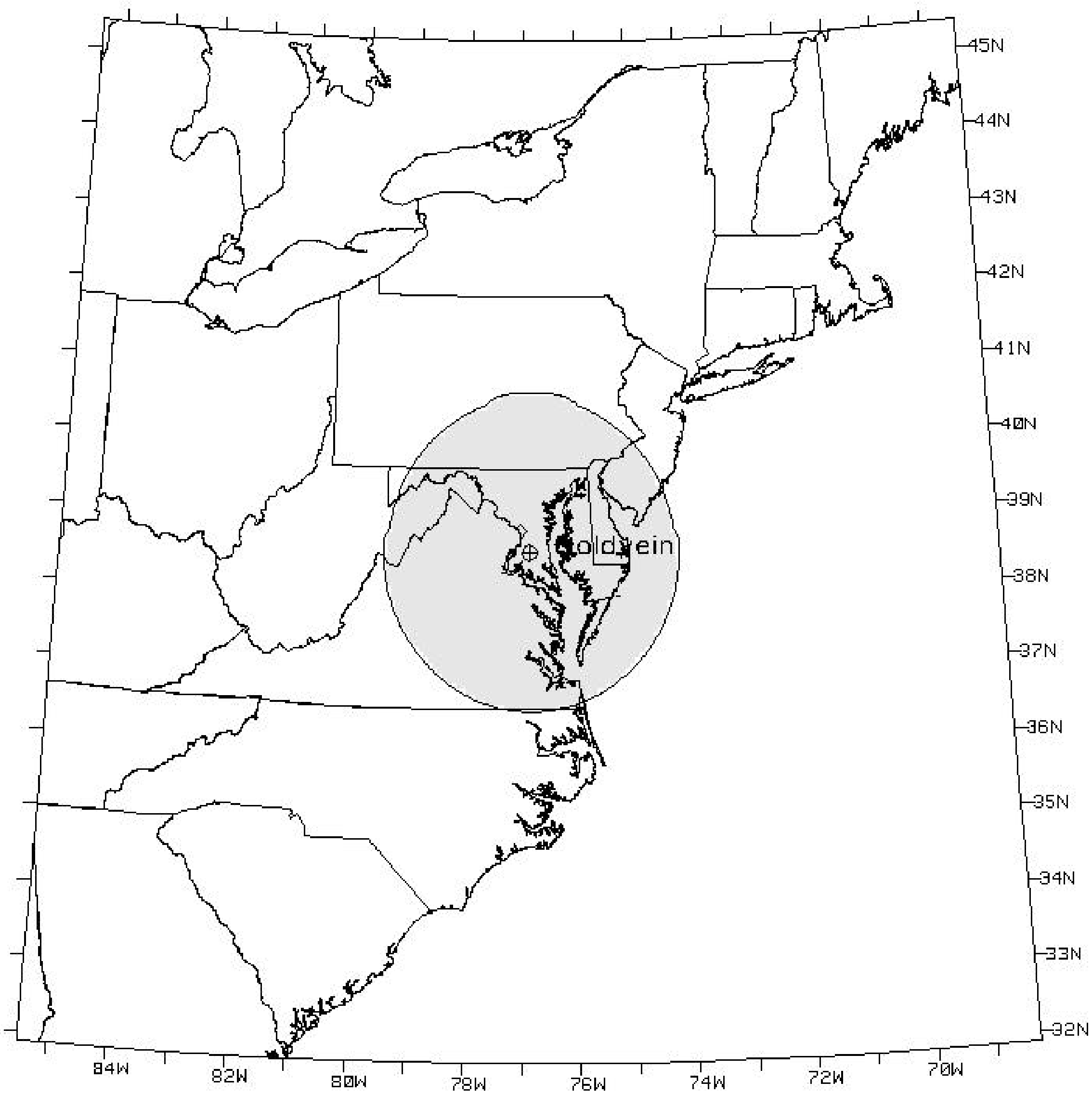

Figure 5.33. Goldwein, VA.

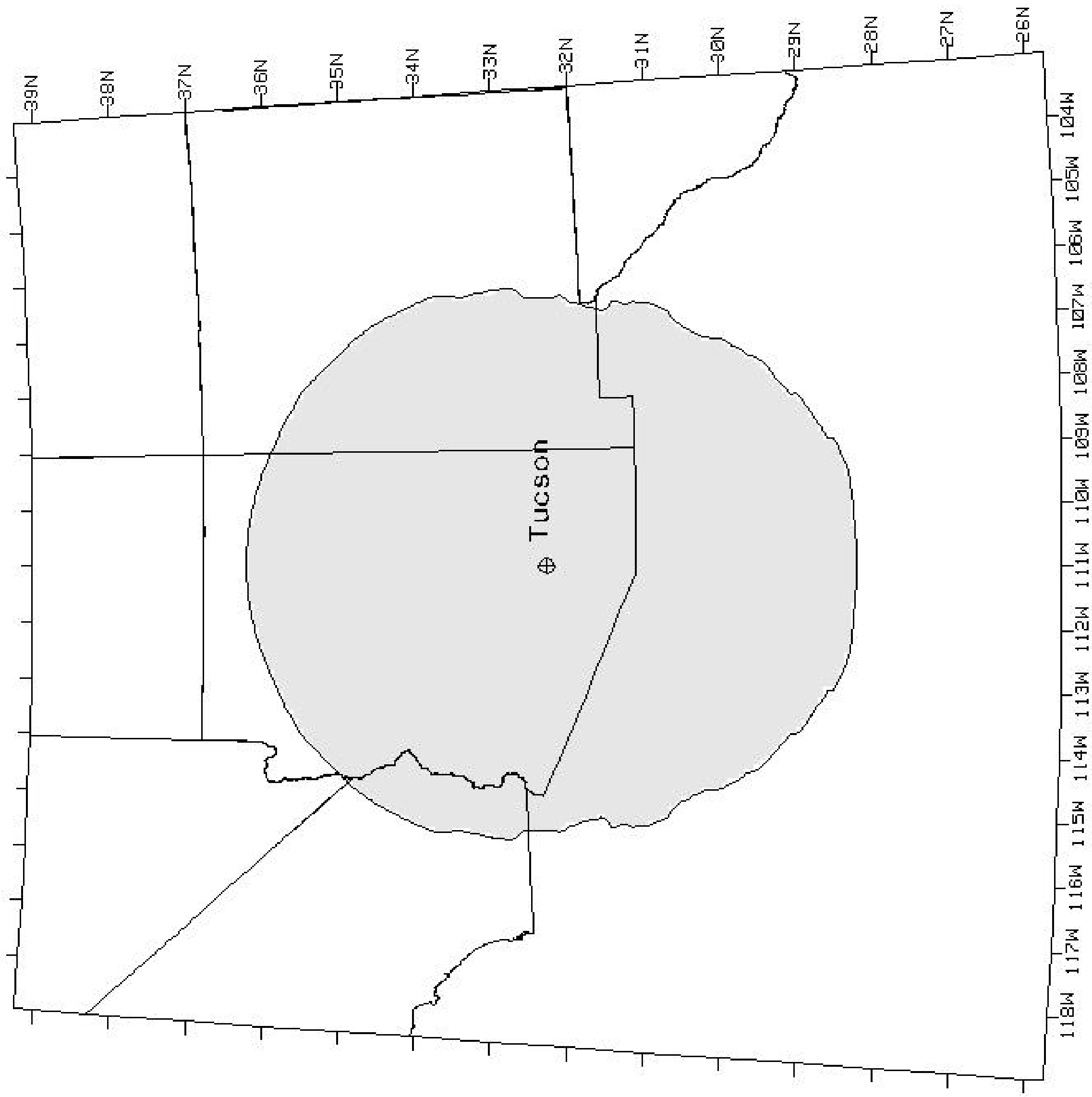

Figure 5.34. Tucson, AZ.

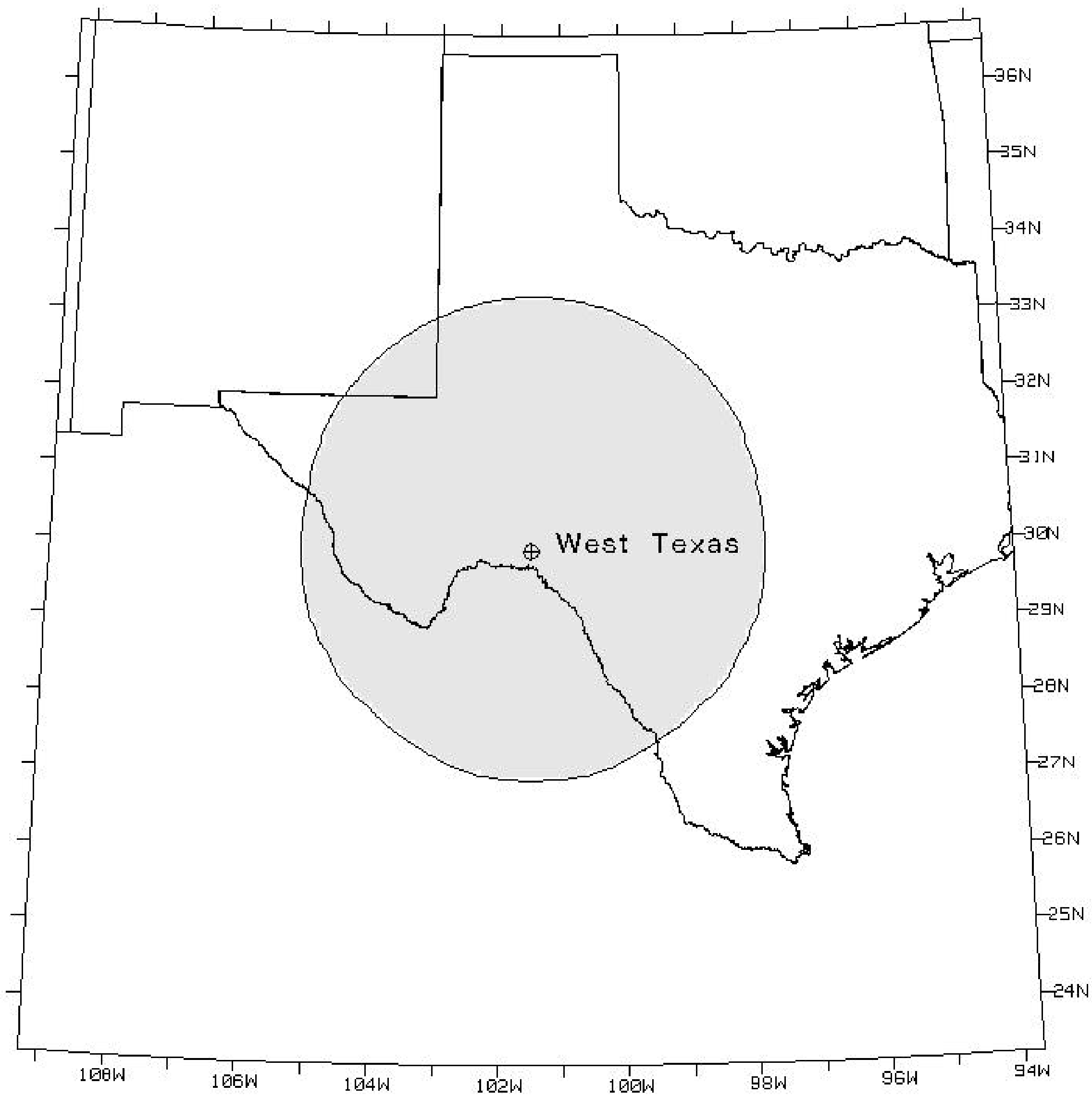

Figure 5.35. West Texas, TX.

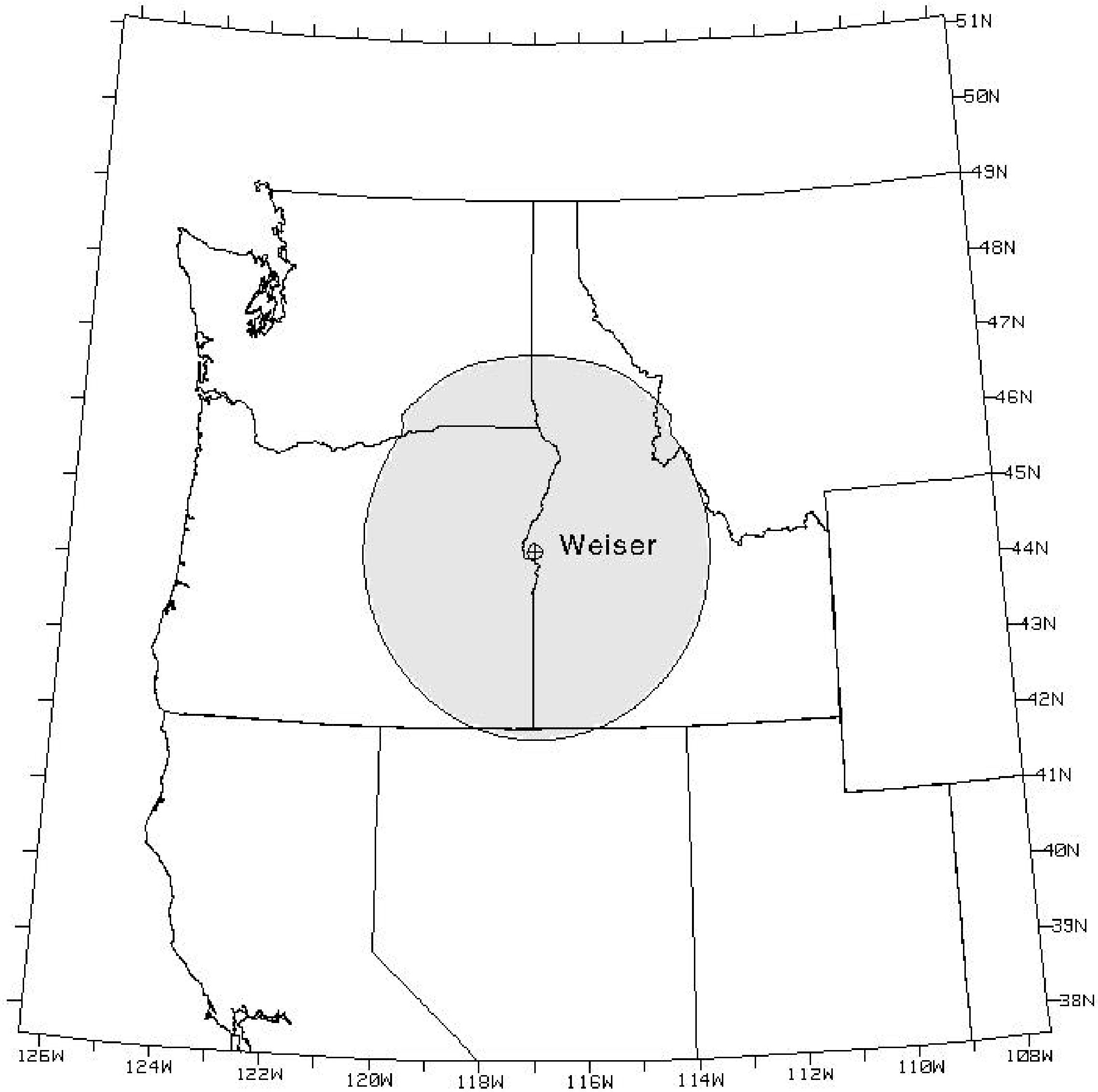

Figure 5.36. Weiser, ID.

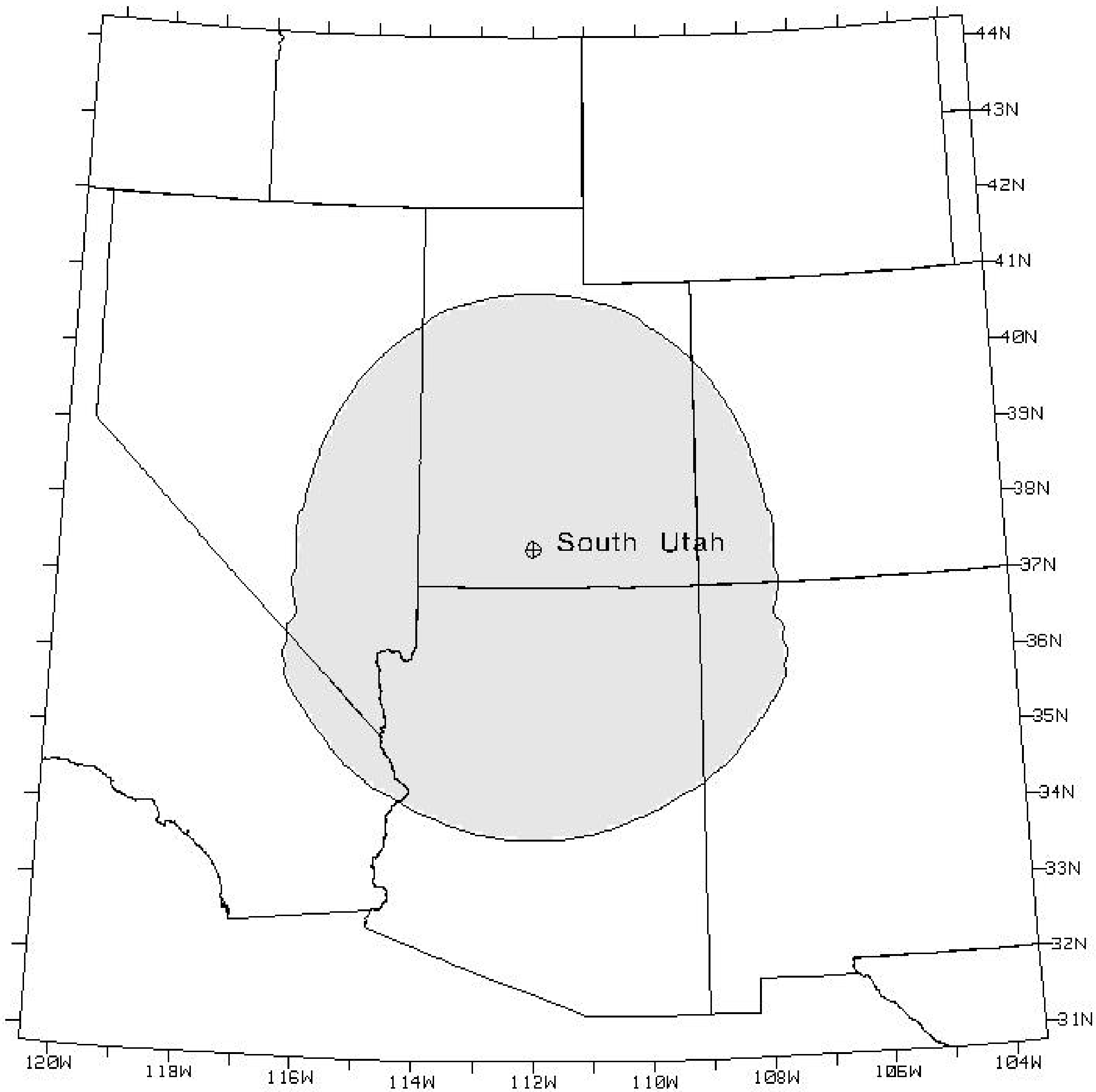

Figure 5.37. South Utah, UT.

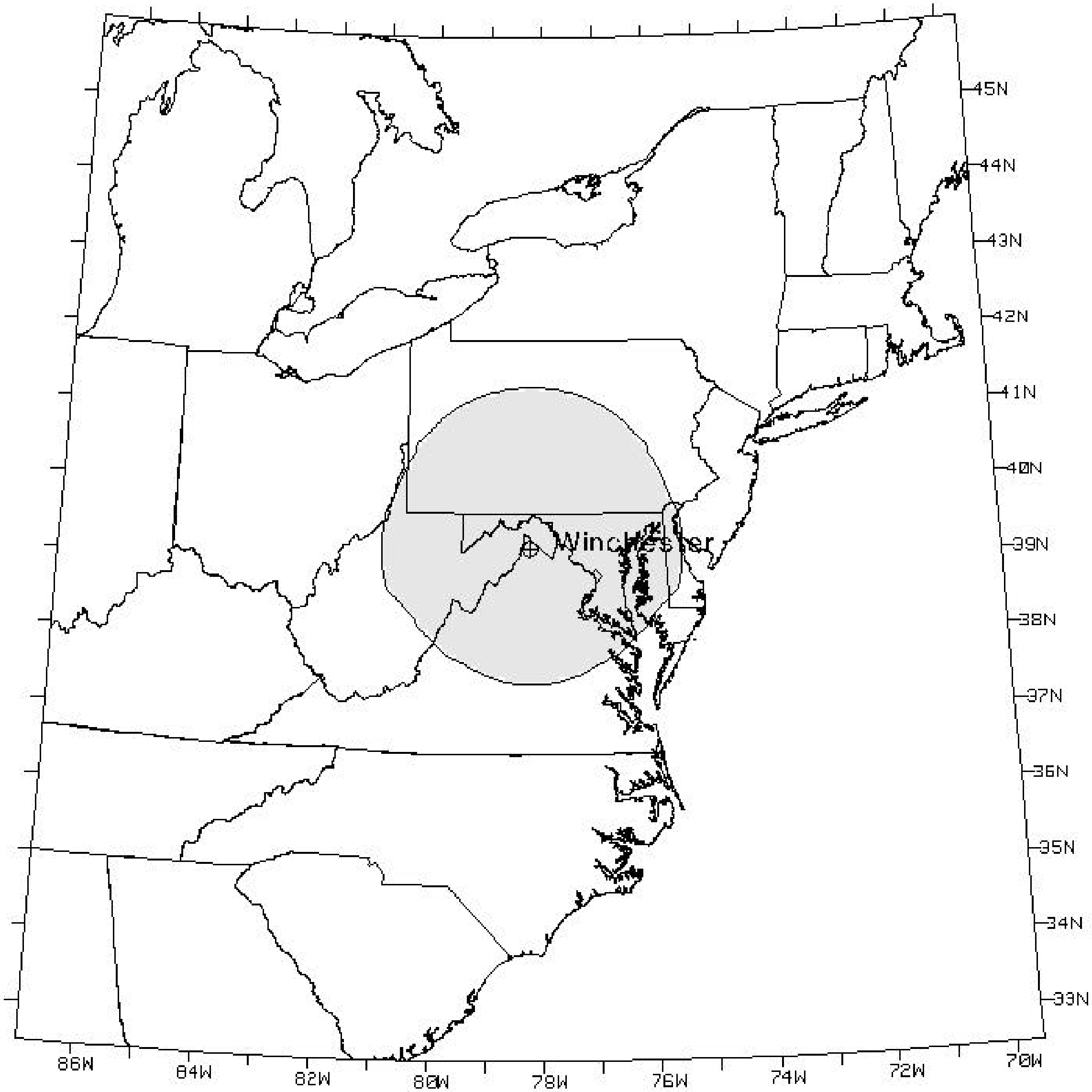

Figure 5.38. Winchester, VA.

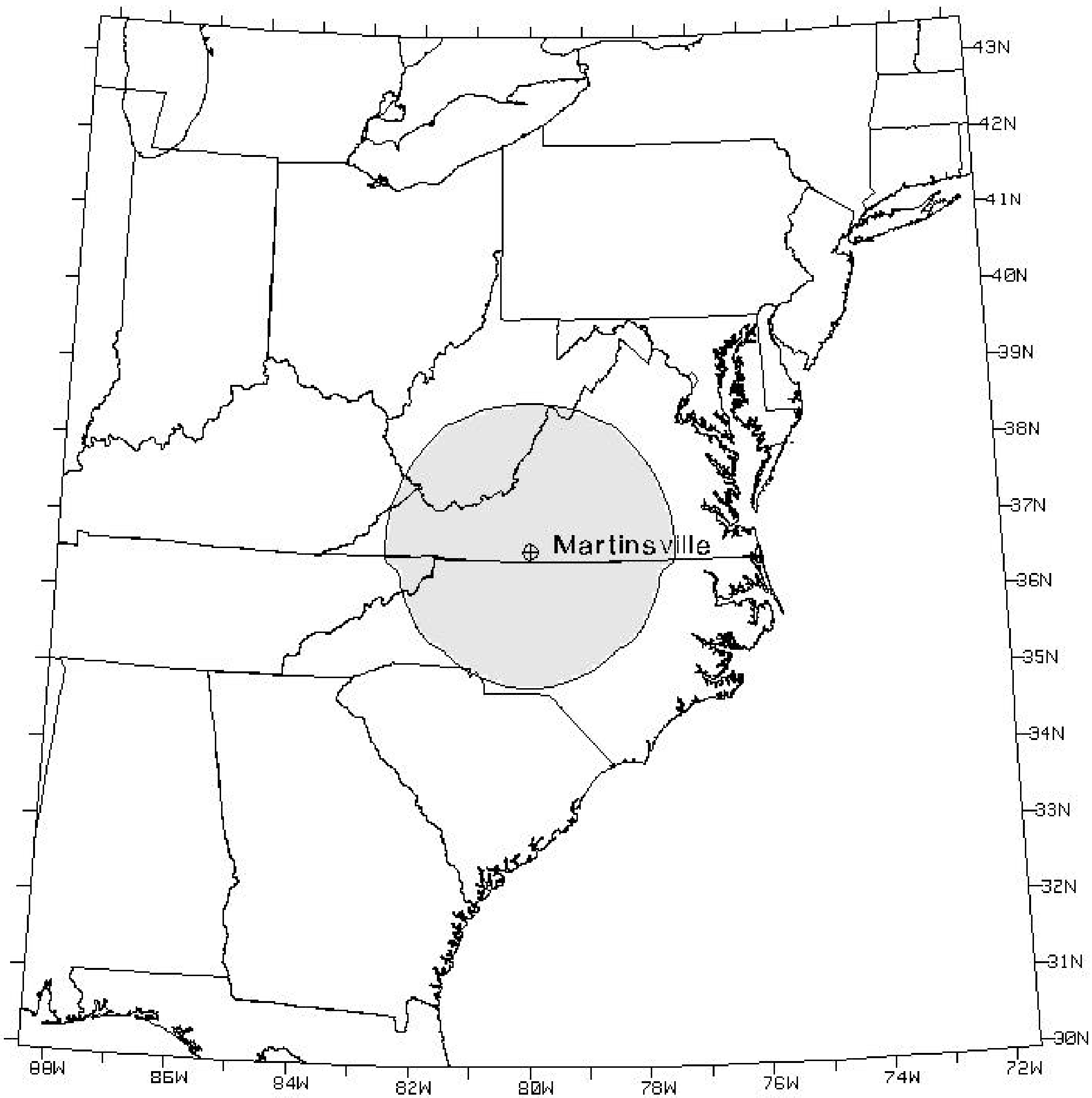

Figure 5.39. Martinsville, VA.

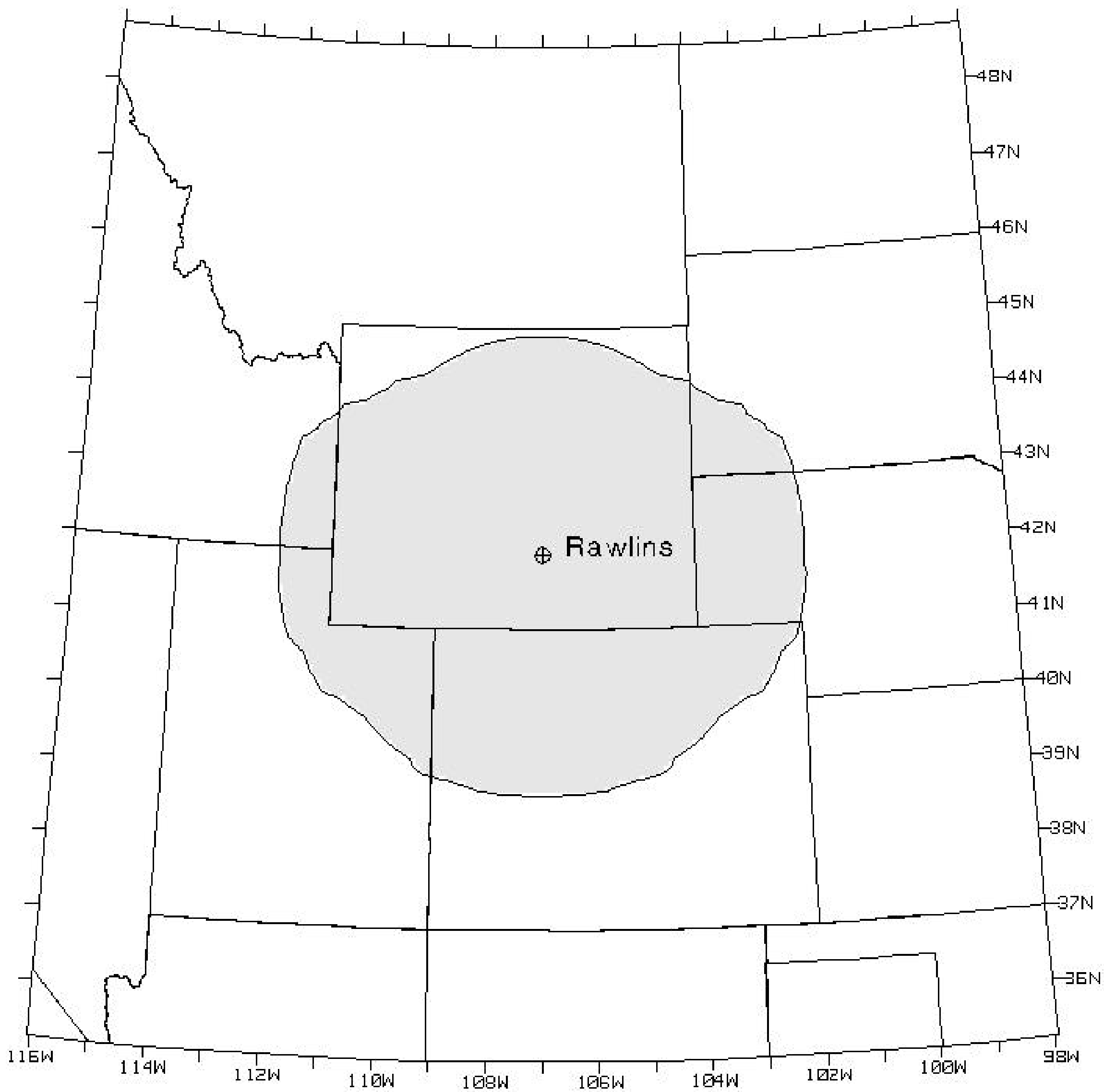

Figure 5.40. Rawlins, WY.

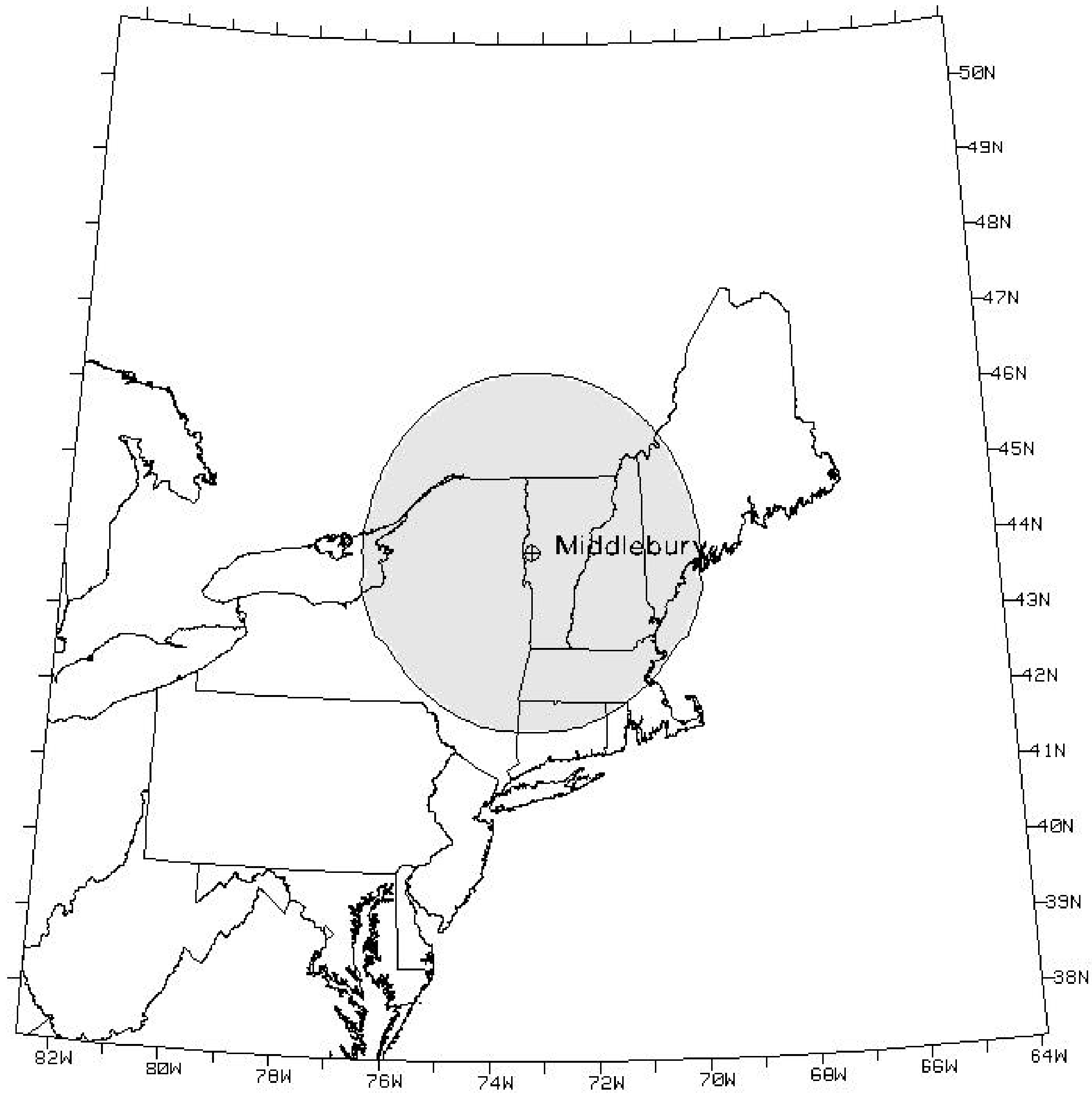

Figure 5.41. Middlebury, VT.

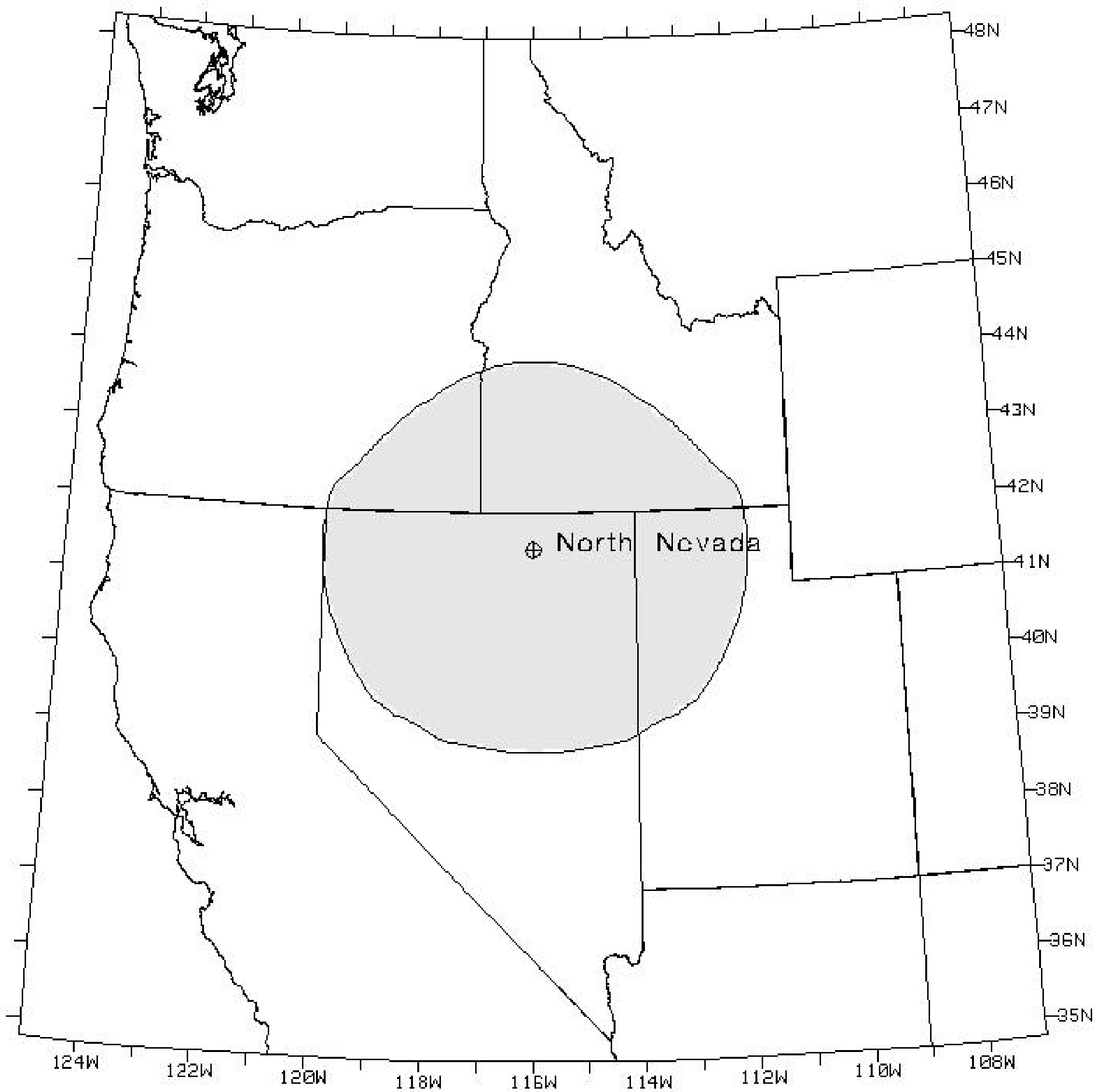

Figure 5.42. North Nevada, NV.

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6
INSTALLATION CONSIDERATIONS

Several factors need to be considered to select the proper DGPS broadcast site location and insure adequate installation of the equipment at the broadcast site. Although a common set of equipment is used at each DGPS broadcast site, some aspects of the installation are specific for a particular site, depending on local conditions. This chapter presents an overview of the factors that will affect the successful installation of a broadcast site, but does not cover the detailed engineering information required to complete the installation. Refer to the U.S. Coast Guard "Differential GPS Broadcast Equipment Technical Manual," GCF-W-1216-DGPS, and related documents for detailed information.

6.1 Site Selection

When determining the suitability of a location for use as a DGPS broadcast site the following factors should be considered:

(a) A geographical location near the location recommended in chapter 5. It should be noted that the recommended DGPS broadcast site locations that have been added to complete the nationwide coverage were selected as optimum locations and at these frequencies, location of the site up to 10 miles from the optimum location will have very little effect on the nationwide coverage plan.

(b) Access to the site by construction and maintenance crews.

(c) Availability of space for a new equipment shelter or existence of a suitable building to serve as a shelter.

(d) Suitability of the site for installation of the radiobeacon transmitting antenna and associated equipment, or existence of a previously installed transmitting antenna.

(e) Availability of suitable reference mast locations.

(f) Physical security of the site.

(g) Legal and environmental issues.

6.2 Site Configuration

The equipment required for a DGPS broadcast site is shown in Figure 6.1. The location selected for the broadcast site must be capable of accommodating this suite of equipment.

The typical layout of an existing GWEN radio transmitter site is shown in Figure 6.2. These existing GWEN radio transmitter sites, recommended for use as DGPS broadcast sites, are listed in Tables 5.2 and 5.4. The drawing shows a typical site and the layout at an individual site may vary due to local topography and site conditions. Additional sites that are required to complete the nationwide DGPS service will have a similar layout, with variations due to local conditions. The DGPS broadcast site element requiring the most area is the broadcast antenna tower and its associated ground plane. At new installations the antenna and ground plane will be designed, considering transmitter power available, antenna efficiency, and local ground conductivity, to provide the specified signal level at a distance of 10 kilometers from the transmitter. Therefore, at new installations the broadcast antenna design will be the determining factor in site layout.

6.3 Broadcast Antenna Installation

The installation of DGPS broadcast sites at existing GWEN radio transmitter sites, listed in Tables 5.2 and 5.4, will not require installation of a broadcast antenna, since an adequate antenna is in place at these sites. New installations, listed in Tables 5.3 and 5.4, that are necessary to complete the nationwide DGPS service, will require that a broadcast antenna and the associated ground plane be designed for the specific site. The antenna will vary to meet the requirements at an individual DGPS broadcast site. The USCG uses a variety of antennas at their DGPS broadcast sites including 60-foot towers, 90-foot towers, 150-foot towers, and 200-foot dual tower systems, depending on the requirements of an individual site. At new installations the antenna and ground plane will be designed, considering transmitter power available, antenna efficiency, and local ground conductivity, to provide the specified signal level at a distance of 10 kilometers from the transmitter.

6.4 Reference Mast Installation

This information will assist in selecting the most reasonable locations for the reference masts that support the GPS antennas. Four GPS antennas, on two reference masts, will be located at each broadcast site, two each for the redundant reference stations and integrity monitors. These four antennas will be mounted in pairs at two locations per site. Each pair will consist of one reference station antenna and one integrity monitor antenna. Under normal operating conditions, the reference station antenna at one location will be used with the integrity monitor antenna at the other location. This is done to reduce the similarity in the multipath received at the reference station and the integrity monitor. The greater the separation between the antennas, the less similarity there will be, the maximum distance practicable should be used. As a general rule, there must be at least a 22-meter distance between the locations of the reference station/integrity monitor antenna pairs. There may be sites where extraordinary considerations will override this desired separation. An offset in the height of the antennas, even of a few feet, will provide some

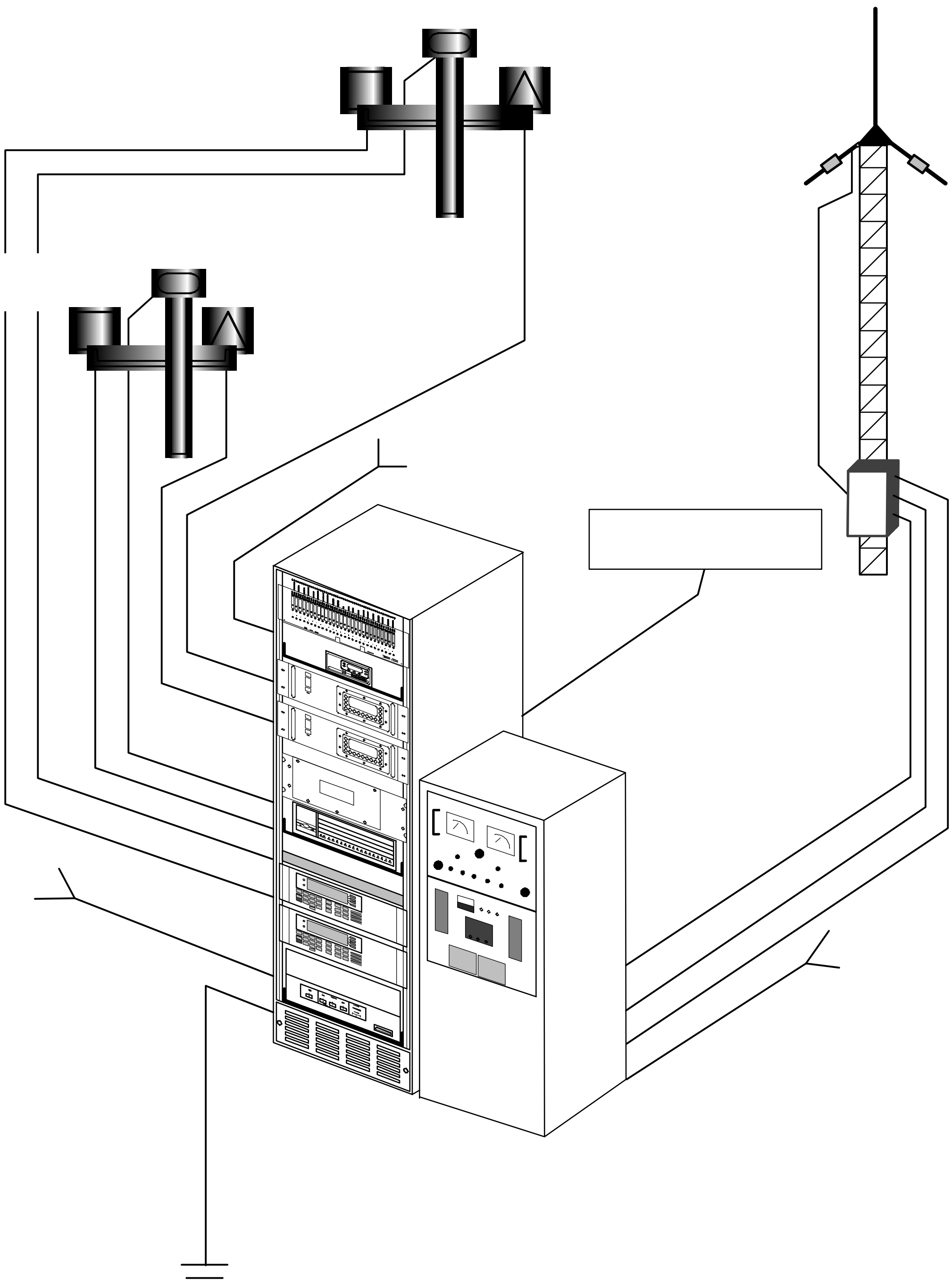

Figure 6.1. DGPS broadcast site equipment .

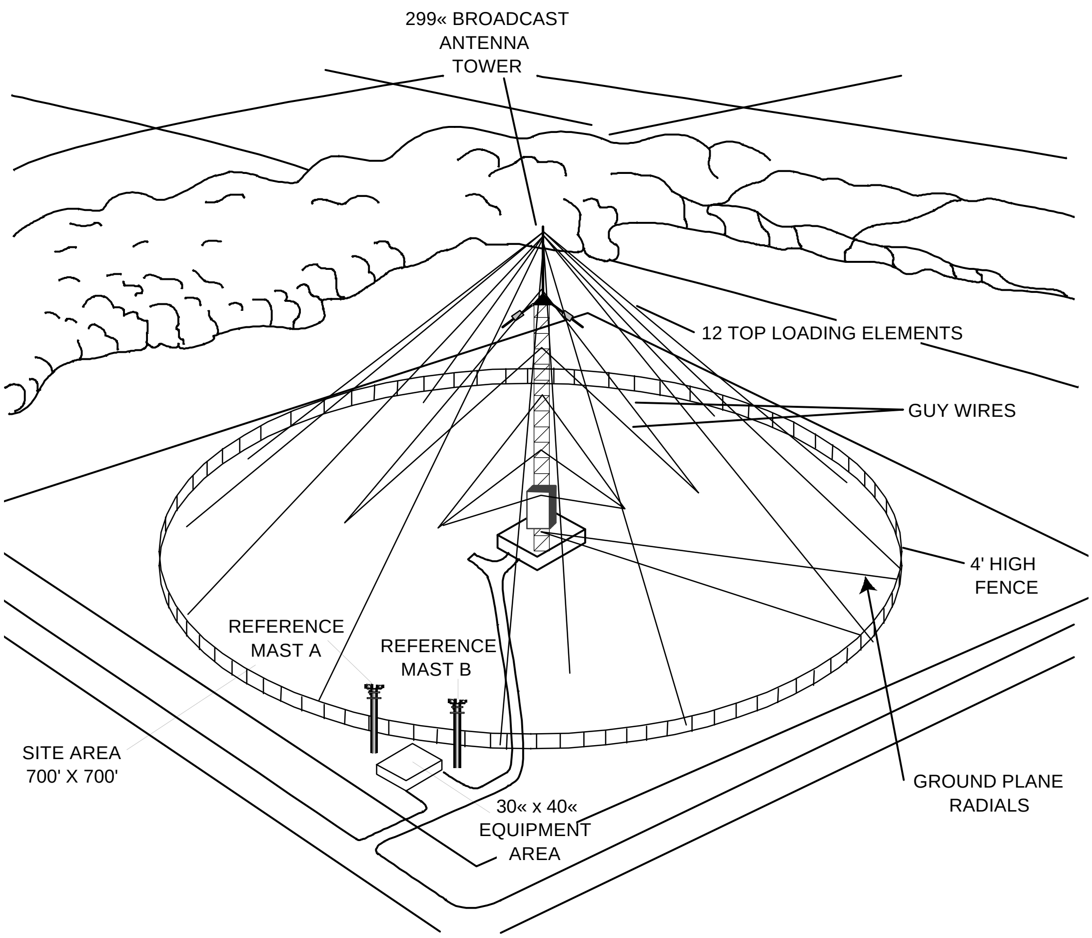

Figure 6.2. Typical existing GWEN radio transmitter site layout.

additional protection. Typically, GPS antennas will be mounted on 3- or 6-meter reference masts. In some cases, higher reference masts may be required to reduce horizon blockage and multipath effects. The reference masts must be sufficiently sturdy to keep sway within ±8 cm.

Due to the nature of the GPS satellite orbits and signal structure, there are two main concerns related to antenna placement. Since the satellites appear in all areas of the sky, shading due to hills, buildings, trees, and other obstructions should be minimized as far as practical. Sky blockage below 7.5 degrees of elevation is not a major concern, because corrections will only be broadcast for satellites above this mask angle. However, it should be noted that satellites below the mask angle will be tracked so that corrections will be ready when they rise above 7.5 degrees. In addition, steps must be taken to reduce the effects of multipath. Multipath effects are caused by reflected signals arriving at the antenna. These reflections are referred to as indirect signals. The signal arriving straight from the satellite is called the direct signal. The best case is when the direct signal is much stronger than all indirect signals combined.[11]

The antenna mounting requirements at each site will be unique depending on the local terrain, existing buildings, and other structures. Once the approximate location for the GPS antennas is determined, an optimum mount must be selected. Antenna mounts will either consist of hardware for attaching the antennas to existing buildings or towers, or require new reference masts

The distance between GPS antenna masts is a trade-off between cable length (30 meters maximum) and reducing the similarity of the multipath environments of the reference station and the integrity monitor. Due to the limited cable length, the antennas will be mounted relatively close to each other. The integrity monitor will notice if the multipath errors are large enough to throw the overall system performance out of tolerance. The integrity monitor will detect a problem for a single satellite whenever more than two satellites are being tracked.

6.5 Survey Requirements

The ability of the DGPS broadcast site to calculate and transmit accurate corrections to the GPS positioning signal relies on knowledge of the exact position of the GPS receive antennas located at the site. The procedure used by the USCG to survey these antenna positions at their existing DGPS broadcast sites is outlined below.

The National Geodetic Survey (NGS) installs geodetic monuments at the DGPS broadcast site to support the surveying of GPS antenna positions. These monuments are permanent survey markers. Two monuments are typically selected with significant separation, this reduces the chance both might be accidently destroyed by construction equipment or erosion. It is also desirable that one be in a publicly accessible location, and the other in a secure location where equipment can be left unattended. It is also desirable, but not required, that the monuments be visible from each other so that surveyors may use traditional optical methods to determine azimuths by using both. Distance of the monuments from the reference station/integrity monitor
reference masts should be kept under a few hundred meters.

Using these monuments, the position of each GPS antenna will be surveyed to determine its exact location within 10 cm. The position survey will use the North American Datum of 1983 (NAD-83). The reference stations GPS antennas geodetic positions must be surveyed to within ±10 cm in order to begin DGPS broadcasting. After the installation, NGS can analyze data in order to verify and refine the initial position survey to ±1 cm or better.

6.6 Shelter Requirements

If the DGPS broadcast site is being installed at an existing GWEN radio transmitter site (Tables 5.2 and 5.4), shelters suitable for equipment installation are available. For new DGPS broadcast site installations (Tables 5.3 and 5.4), a shelter to adequately house the DGPS equipment must be provided. Where possible, existing buildings or shelters should be utilized. If a new shelter is required, a fiberglass building with dimensions: 8 feet high, 15 feet wide, and 10.5 feet deep, is recommended, assuming an emergency power generator does not exist.

6.7 Equipment Rack Installation

The DGPS equipment rack and the radiobeacon transmitter rack should be installed inside the equipment shelter, allowing adequate working space on all sides of the racks. The preferred placement is to locate the DGPS equipment rack to the left of the radiobeacon transmitter, as shown in Figure 6.1. If possible the equipment rack should be mounted on a pedestal that will allow AC power to enter the rack through the base. If the AC power cannot be routed through the base of the rack it may be brought into the top of the rack. At the existing GWEN radio transmitter sites, equipment racks are in place, and the DGPS equipment and the radiobeacon transmitter may be mounted in these racks. Detailed instructions for installing the DGPS equipment in the racks, and interconnecting the equipment can be found in the U.S. Coast Guard "Differential GPS Broadcast Equipment Technical Manual."

6.8 Communications Requirements

One high-speed data line is required at the DGPS broadcast site to permit communication with the control station. This is an X.25, 9600 bps, 4-wire line supplied by the local service provider. One voice telephone line should be available for voice communications. These communication lines are brought into the equipment shelter.

6.9 Power Requirements

The DGPS broadcast site requires 115/230 VAC, 60 Hz commercial power as the primary power source. The radiobeacon transmitter rack, DGPS equipment rack, antenna tuning unit, lighting, service outlets, and environmental control systems should all have dedicated circuit breakers. The power requirements for the radiobeacon transmitter is determined by the equipment used at a particular location. If a USCG radiobeacon transmitter is used the power requirement varies from

450 VA to 6400 VA, depending on the transmitter power. Similar variations would be expected for other transmitters that might be used. The antenna tuning unit associated with each radiobeacon transmitter requires from 15 VA to 60 VA. The DGPS equipment rack requires a 20 amp circuit breaker. Circuit breakers for lighting and service outlets should be 20-amp. The power requirements for environmental controls are site specific and should be determined during design of the site. A power conditioner and filter should be part of the overall site design. This equipment will mitigate potential problems caused by brownouts, power fluctuations, and noise on the commercial power line. The required power is available at all existing GWEN radio transmitter sites.

An uninterruptible power system is required at each DGPS broadcast site to provide on-line uninterruptible AC power to the vital equipment located in the DGPS equipment rack. The uninterruptible power system does not provide uninterruptible power to the equipment rack cooling fan or the radiobeacon transmitter. The standard USCG DGPS broadcast site uninterruptible power system has a battery backup unit, located directly above, which will provide a minimum of 10 minutes power at full load. In the event of a loss in primary power, the uninterruptible power system will give the DGPS broadcast site monitor time to notify the control station of the site's power status but will not, by itself, allow the site to continue DGPS broadcasts. If the DGPS broadcast site is installed at an existing GWEN radio transmitter site the uninterruptible power system and battery backup unit will be available external to the DGPS equipment rack. In this case, the external uninterruptible power system should be incorporated into the DGPS system to support operation in the event of power failure.

At any DGPS broadcast site where power is not reliable, an emergency generator should be installed to provide sufficient backup power to the radiobeacon and DGPS rack in the event of a prolonged commercial power outage. The generator should be rated between 125 and 165 percent of the site's load, including environmental controls. At the existing GWEN radio transmitter sites this emergency generator is available, along with above ground fuel storage tanks.

6.10 Environmental Sensors

Environmental sensors are installed at each DGPS broadcast site so that conditions at the site can be monitored by the control station. The normal set of sensors include temperature sensors, humidity sensors, fire detection, and intrusion detection.

The temperature sensor is normally set to provide alarms if the temperature inside the shelter is above 90 degrees F or below 40 degrees F.

The humidity sensor is normally set to alarm if the humidity inside the shelter exceeds 80%.

The fire detectors are connected to the fire detection/suppression system. This installation will vary from site to site depending on the type of fire detection/suppression system installed.

The intrusion detectors are normally connected to the primary entrance and any windows in the shelter, to alarm on unauthorized entry. In areas where the DGPS equipment is located with other equipment, the intrusion detectors may be mounted on the DGPS equipment rack doors.

All of the environmental sensors described above are available at existing GWEN radio transmitter sites listed in Tables 5.2 and 5.4.

6.11 Fire Detection/Suppression

If a DGPS broadcast site is unmanned, it should be equipped with a fire detection/suppression system. The DGPS broadcast site monitor is designed to monitor the fire detection status and provide an alarm to the control station.

6.12 Physical Security

The DGPS broadcast site should be provided with security measures that will restrict access to the site and equipment on the site. Security fencing is available at all GWEN radio transmitter sites.

6.13 Broadcast Antenna Tower Lights

The requirements for broadcast antenna tower lighting will depend on the antenna tower used at a DGPS broadcast site. The 299-foot towers that are located at the existing GWEN radio transmitter sites are equipped with a white strobe light at the top to comply with Federal Aviation Administration safety standards.

6.14 Frequency Assignments

The radiobeacon transmitters operate in the 285 to 325 kHz, medium frequency band. This is a shared band, allocated for radionavigation applications, with civil and Government users in the band. The operating frequencies recommended for new DGPS broadcast sites have been selected to avoid interference with other DGPS broadcast sites and with Federal Aviation Administration beacons, civil radiobeacons licensed by the Federal Communications Commission, Canadian DGPS beacons, and Canadian aviation beacons, that operate in this frequency band. The recommended new frequencies are noted in Tables 5.1 through 5.4. Since frequency assignments in this band are dynamic, the situation will need to be reevaluated when application for a frequency assignment is made at a specific location.

7

DGPS BROADCAST SITE SIGNAL COVERAGE FOR ALASKA AND HAWAII

Chapter 5 presented the requirements for DGPS broadcast sites necessary to provide the DGPS correction signal to all surface users in the continental U.S. This chapter presents the requirements for DGPS broadcast sites necessary to provide the DGPS correction signal to surface users in Alaska and Hawaii. The basis of the DGPS service in these two states is the network of DGPS broadcast sites now in operation by the U.S. Coast Guard (USCG), providing DGPS correction signal coverage to coastal areas and harbors. A medium frequency radio propagation model was utilized along with the operating parameters of each DGPS broadcast site, to predict the signal coverage of the individual broadcast sites in these areas. The signal coverage of the individual sites were then combined to determine the predicted signal coverage that would be obtained with the DGPS broadcast sites that are in operation. This radio propagation model was then used to determine the signal coverage that would be provided by Ground Wave Emergency Network (GWEN) type radio transmitter sites that were added to complete the signal coverage.

In order to provide the most cost effective solution to the implementation of DGPS service in Alaska and Hawaii, maximum use was made of existing DGPS broadcast sites. The signal coverage obtained is presented below in four stages:

1. Existing USCG DGPS signal coverage for Alaska
2. DGPS signal coverage for Alaska obtained by adding two GWEN sites
3. Existing USCG DGPS signal coverage for Hawaii

7.1 USCG DGPS Signal Coverage for Alaska

The basis of the Alaska DGPS service is the network of DGPS broadcast sites now in operation by the USCG, providing DGPS correction signal coverage to coastal areas, and harbors. The network was originally designed to provide signal coverage for harbor and harbor approach areas, and other critical waterways for which the USCG provides aids to navigation. The radiobeacon signal coverage provided by this network is shown in Figure 7.1. The locations and operating parameters of the DGPS broadcast sites making up this network is described in Table 7.1.

7.2 Additional DGPS Broadcast Sites Required for Signal Coverage in Alaska

The DGPS correction signal coverage provided by adding two GWEN type radio transmitter sites to the existing USCG DGPS broadcast sites is shown in Figure 7.2. The two added sites provide DGPS signal coverage along the major railroad line from Anchorage to Fairbanks. The locations and operating parameters of these broadcast sites are described in Table 7.2. The area of redundant signal coverage for Alaska, provided by this network, is shown in Figure 7.3.

7.3 USCG DGPS Signal Coverage for Hawaii

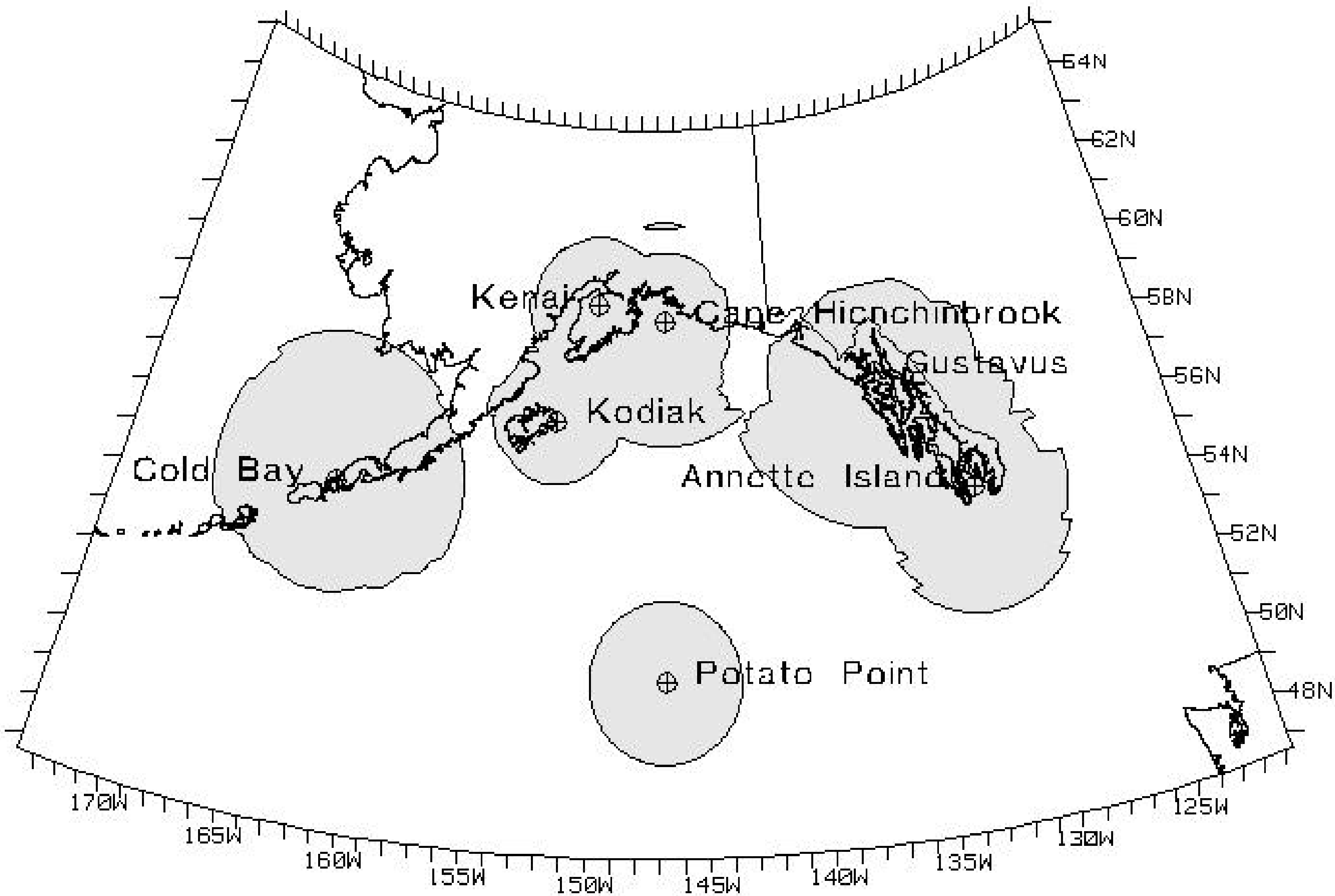

Figure 7.1. Predicted signal coverage for existing USCG DGPS broadcast sites in Alaska.

Table 7.1 USCG Alaska DGPS broadcast site information.

Broadcast Site	Frequency	Power	Latitude	Longitude
	kHz	W (ERP)	(N)	(W)
Cape Hinchinbrook, AK	292	27	60 14 18	146 38 48
Annette Island, AK	323	64	55 04 11	131 35 52
Cold Bay, AK	289	64	55 15 25	162 46 05
Gustavus, AK	288	64	58 25 20	135 42 10
Kenai, AK	310	64	60 35 50	150 13 01
Kodiak, AK	313	64	57 37 08	152 11 21
Potato Point, AK	298	8	51 03 24	146 41 48

Table 7.2 GWEN radio transmitter sites added for Alaska.

Broadcast Site	Frequency	Power	Latitude	Longitude
	kHz	W (ERP)	(N)	(W)
Gold Creek, AK	320	300	62 75 00	149 67 00
Anderson, AK	316	300	64 33 00	149 25 00

The basis of the Hawaii DGPS service is the network of DGPS broadcast sites now in operation by the USCG, providing DGPS correction signal coverage to coastal areas, and harbors. The network was originally designed to provide signal coverage for harbor and harbor approach areas, and other critical waterways for which the USCG provides aids to navigation. The radiobeacon signal coverage provided by this network is shown in Figure 7.4. The locations and operating parameters of the DGPS broadcast sites making up this network is described in Table 7.3.

7.4 Frequency Assignments

Existing USCG DGPS broadcast sites have an operating frequency assigned in the 285 to 325 kHz band. These assignments are noted in Tables 7.1 and 7.3. The operating frequencies recommended for new DGPS broadcast sites have been selected to avoid interference with other DGPS broadcast sites, and with Federal Aviation Administration beacons and FCC beacons that operate in this frequency band. The recommended new frequencies are noted in Table 7.2.

Table 7.3 USCG Hawaii DGPS broadcast site information.

Broadcast Site	Frequency	Power	Latitude	Longitude
	kHz	W (ERP)	(N)	(W)
Kokole Point, HI	300	230	22 03 30	159 46 34
Upolu Point, HI	285	20	20 14 48	155 53 12

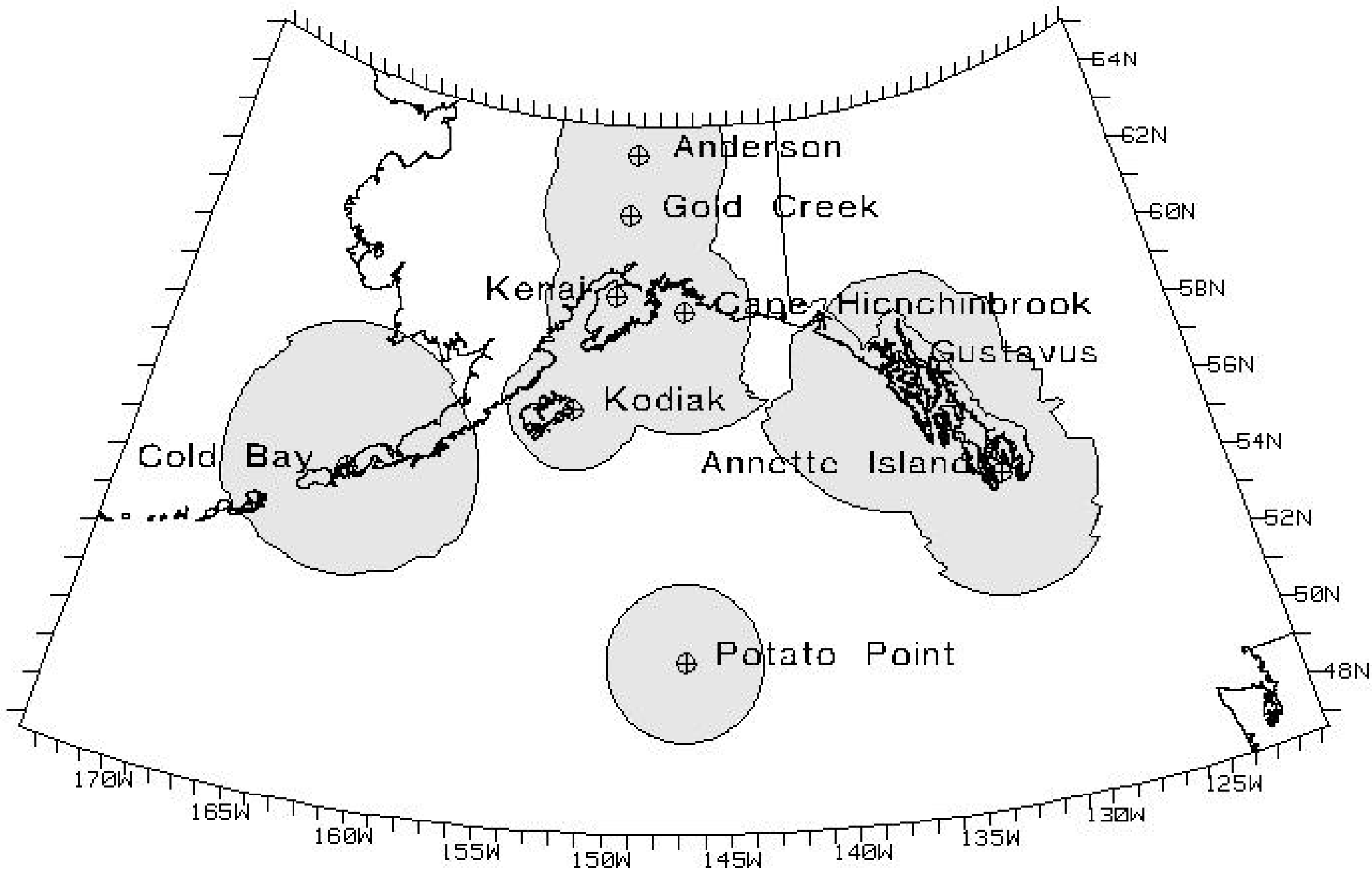

Figure 7.2. Predicted signal coverage for Alaska with 2 GWEN radio transmitter sites added to the USCG DGPS broadcast sites.

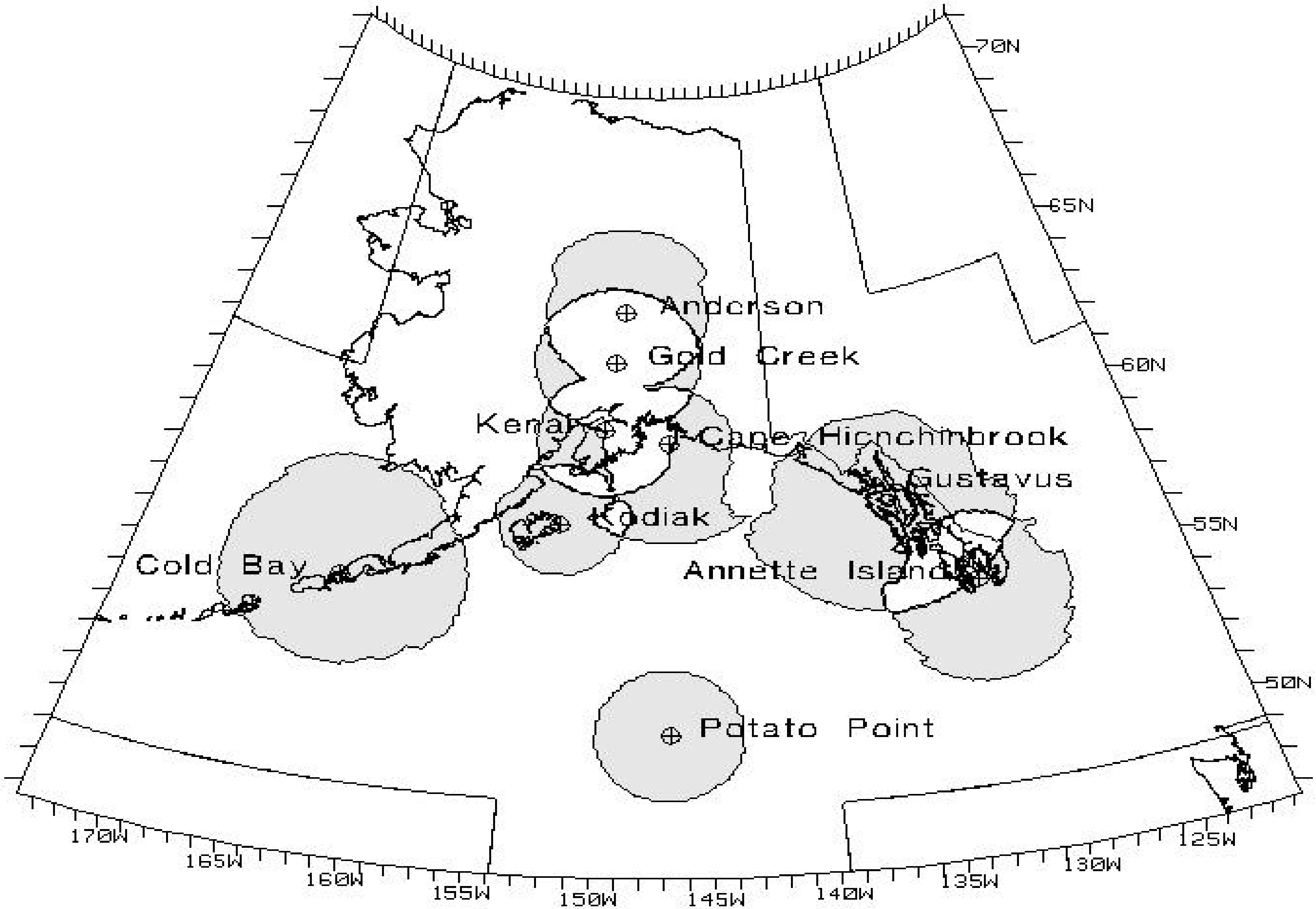

Figure 7.3. Predicted redundant signal coverage for Alaska.

7.5 Individual DGPS Broadcast Site Signal Coverage

The Figures 7.5 and 7.6 show the predicted signal coverage for individual DGPS broadcast sites that will be required to complete the signal coverage for Alaska DGPS service.

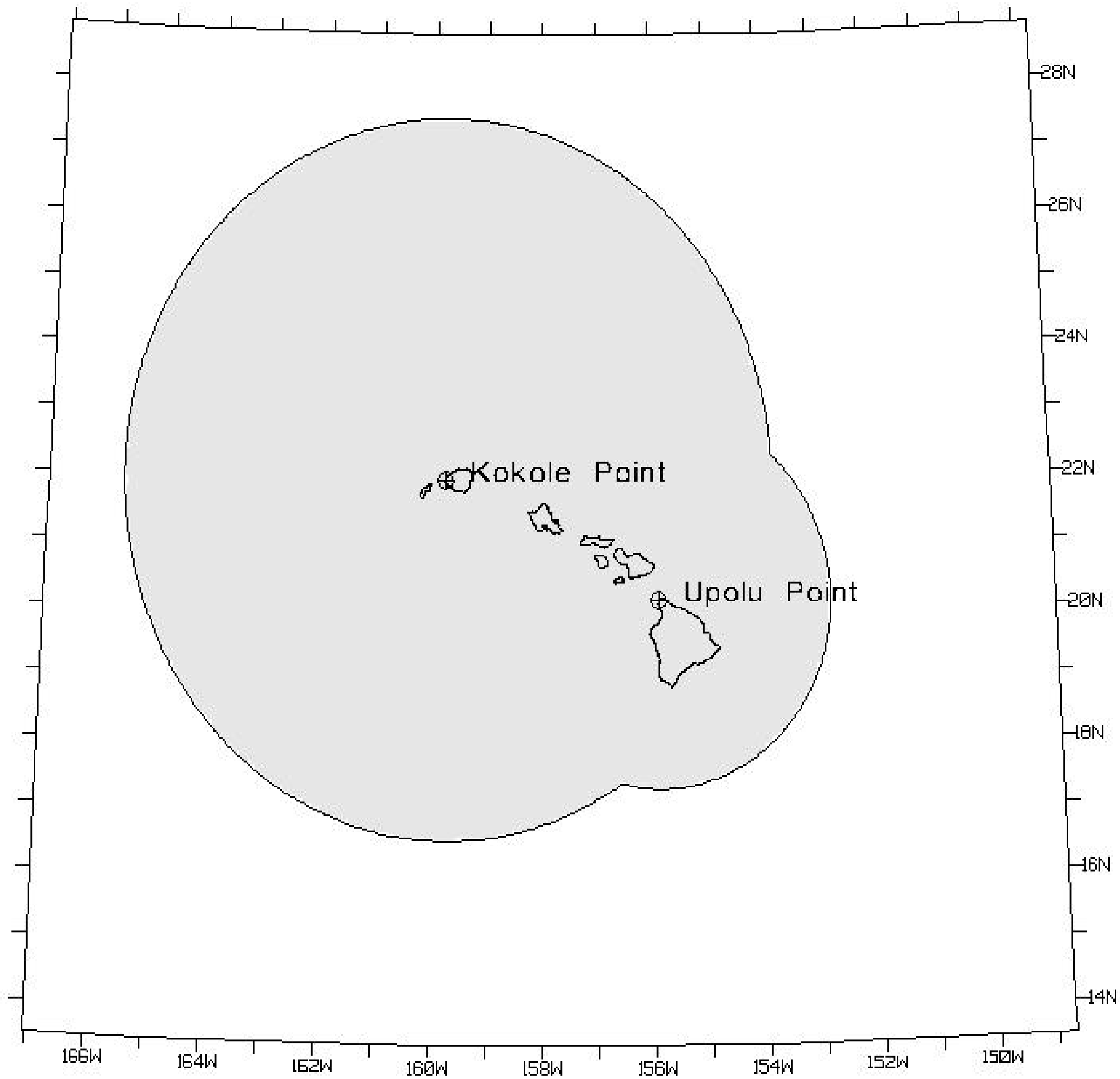

Figure 7.4. Predicted signal coverage for existing USCG DGPS broadcast sites in Hawaii.

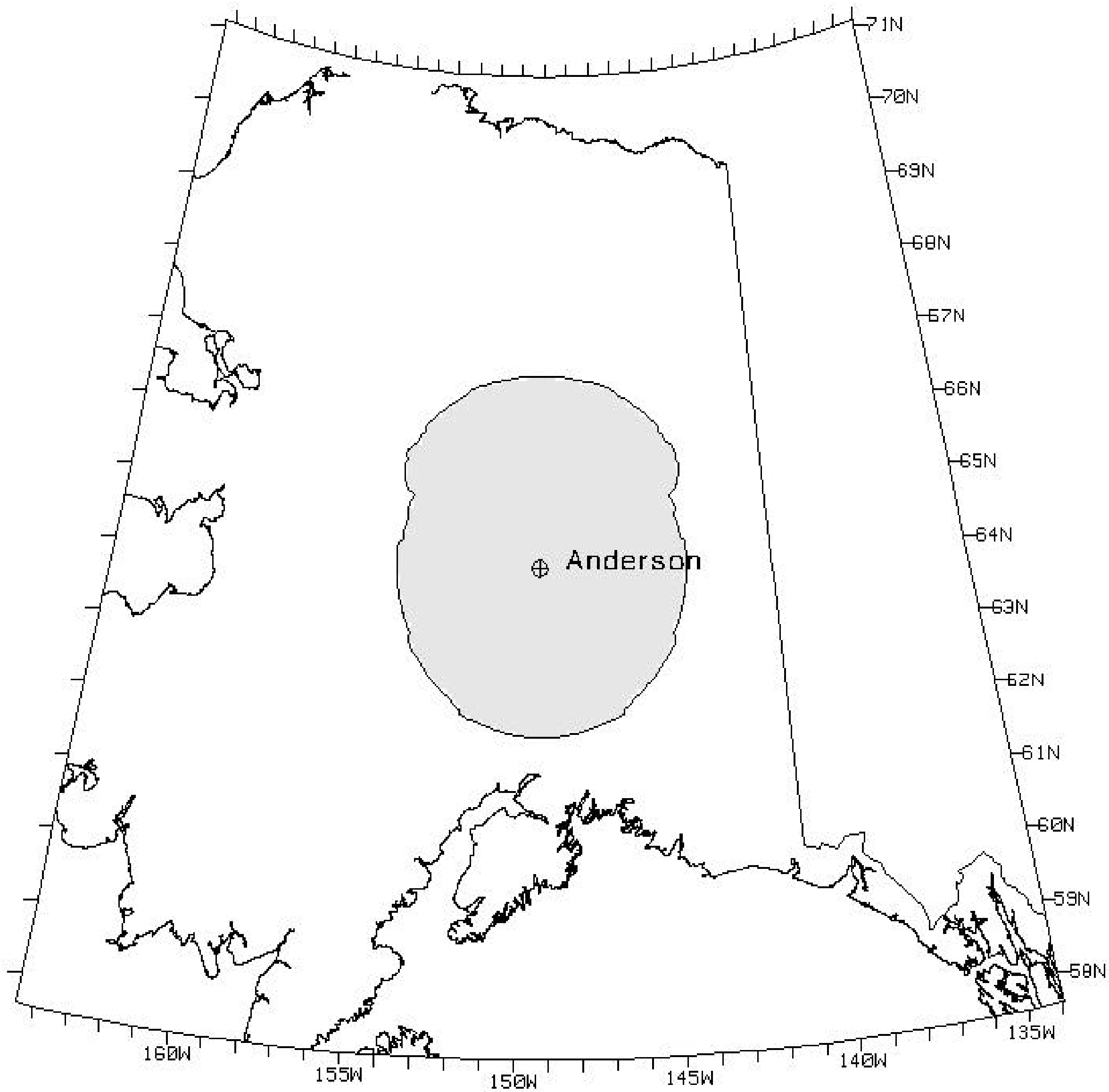

Figure 7.5. Anderson, AK.

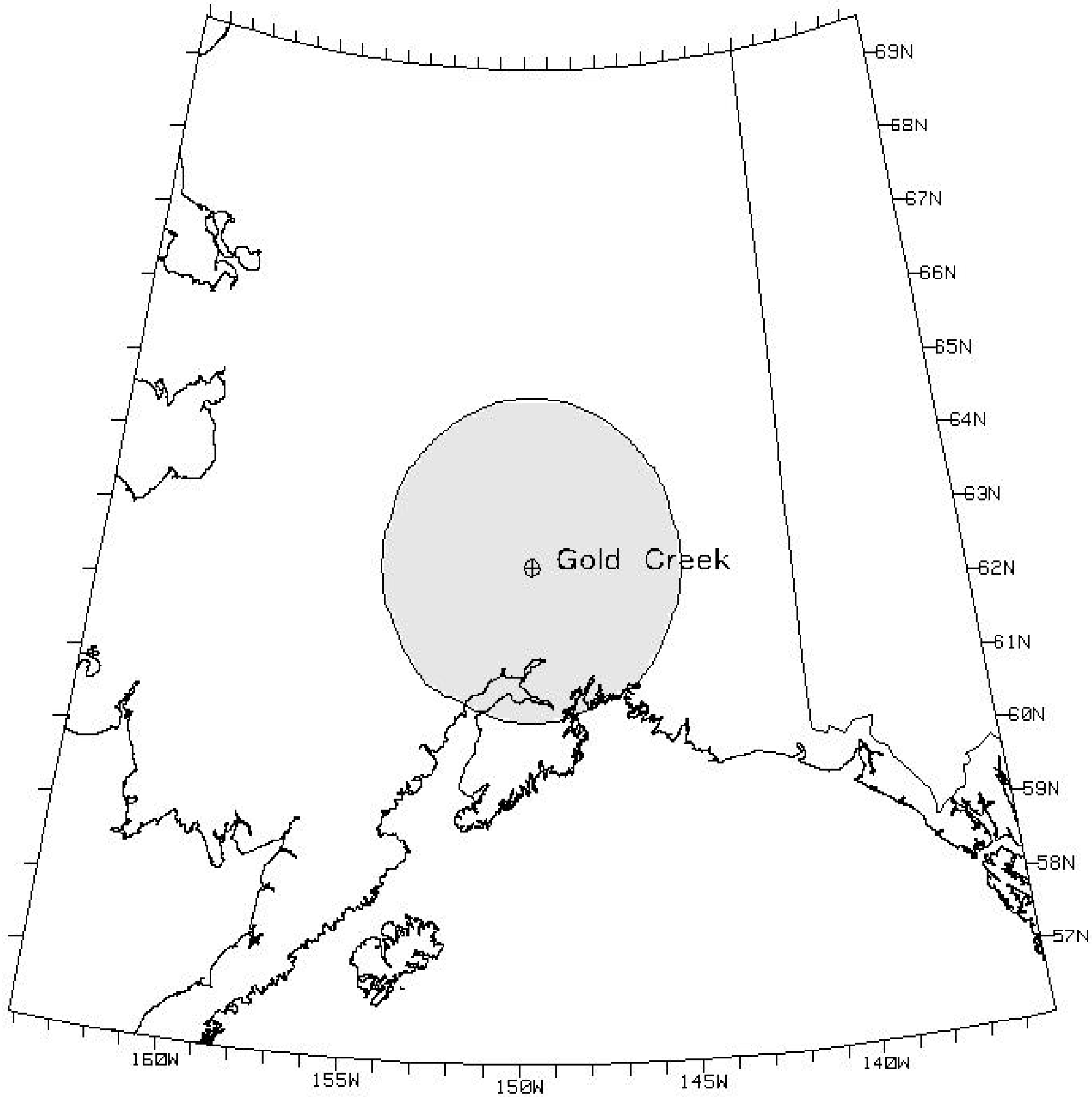

Figure 7.6. Gold Creek, AK.

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